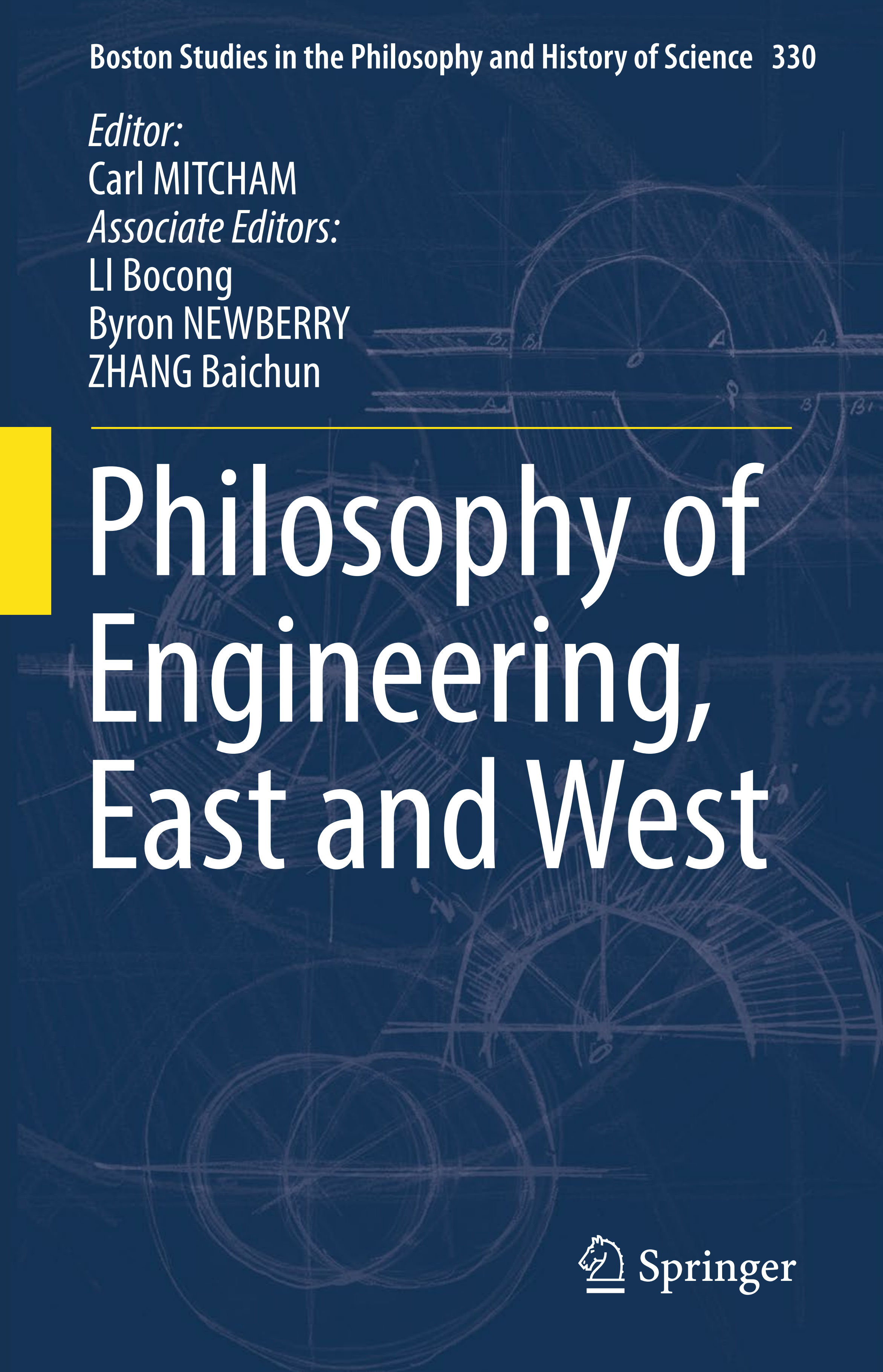

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Philosophy of Engineering, East and West

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Preface

This set of papers grows out of the Forum on Philosophy, Engineering, and Technology that took place in Beijing, China, November 2–4, 2012. The conference was cochaired by Philosopher Li Bocong and Engineer Byron Newberry and hosted by the University of Chinese Academy of Sciences at the Friendship Hotel in the Haidian District. There were more than 40 presentations with approximately 150 participants from 15 countries.

The Forum on Philosophy, Engineering, and Technology (fPET) itself grew out of a series of Workshops on Philosophy and Engineering (WPE) that were initiated in 2006 when Mechanical Engineer Taft Broome at MIT, on sabbatical from Howard University in Washington, DC, convened a small group of engineers and philosophers. The aim was to consider approaches to promoting the engineering-philosophy interaction more vigorously than had been taking place in the Society for Philosophy and Technology (SPT) and its biannual odd-year international conferences. Broome felt strongly that SPT was not sufficiently open to engineers and engineering. The next year, in the summer of 2007, the SPT conference hosted by the University of South Carolina invited Broome to present his ideas. In response, in the fall of 2007, philosophers and engineers at Delft University of Technology in the Netherlands organized and hosted the first WPE.

In 2008, a second WPE was hosted by the Royal Academy of Engineering in London, followed with a WPE track at SPT 2009 at Twente University in the Netherlands. Discussions at WPE 2008 and others that followed, stimulated especially by the interests of Electrical Engineer David Goldberg from the University of Illinois, led to a modest reconfiguring of the effort. The result was the new fPET name and a commitment to organize biannual fPET conferences on even-numbered years as a complement to SPT conferences held on odd-numbered years. In fall 2010, the first fPET conference was hosted by the Hennebach Program in the Humanities at the Colorado School of Mines in Golden, Colorado.

The proceedings of these three conferences—WPE 2007, WPE 2008, and fPET2010—along with some related papers from SPT 2009, were collected in the following two volumes published in the Philosophy of Engineering and Technology series edited by Pieter Vermaas:

- Ibo van de Poel and David E. Goldberg, eds., with Michael Davis, Billy Vaughn Koen, Carl Mitcham, and P. Aarne Vesiling, associate eds. *Philosophy and Engineering: An Emerging Agenda*. Dordrecht: Springer, 2010. Pp. xvii +361. This included 28 papers by 32 contributors from 9 countries.
- Diane P. Michelfelder, Natasha McCarthy, and David E. Goldberg, eds. *Philosophy and Engineering: Reflections on Practice, Principles and Process*. Dordrecht: Springer, 2013. Pp. xix + 431.
  This included a foreword and 30 papers by 38 contributors from 9 countries.

The current proceedings volume, although the first to appear in Boston Studies in the Philosophy of Science, is thus the third in a related series. It is also the third in a series in the Boston Studies devoted to the philosophy of technology. The two previous related volumes are as follows:

- Paul T. Durbin and Friedrich Rapp, eds. *Philosophy and Technology*. Pp. xiv + 343. Boston Studies in the Philosophy and History of Science, Vol. 80 (1983).
  This included an introduction and 22 papers by 23 contributors from 2 countries (Germany and the United States).
- Carl Mitcham and Alois Huning, eds. *Philosophy and Technology II: Information Technology and Computers in Theory and Practice*. Pp. xxii +352. Boston Studies in the Philosophy and History of Science, Vol. 90 (1986).
  This included an introduction and 20 papers by 23 contributors from 3 countries (France, Germany, and the United States), followed by an annotated bibliography.

In comparison with all four of these previous publications, the current volume is the first in which the majority of contributors come from outside North America and Europe and the first to be coedited by such an interdisciplinary team of scholars based in philosophy, engineering, and history. There are 20 contributors from China, nine from the United States, four from Australia, three from Brazil, two from France and from Italy, and one each from Germany, the Netherlands, and the United Kingdom, that is, 24 from the Asia-Pacific region, 15 from North America and Europe, and three from Latin America. Unfortunately, of the 43 total contributors, only 12 are based in engineering. Nevertheless, we see this volume as opening a new chapter in the intellectual dialogue between philosophy and engineering and especially promoting East-West collaborative engagements.

Because of the large number of papers authored by nonnative English speakers and a commitment to help these authors give their arguments a fluent presentation, we have put extensive effort into working with them to revise and edit their articles. In this regard, Katherine Robert has been exceptionally helpful. Without her effort we would not have been able to complete this task.

At the same time, we wish to apologize to our authors for the long delay involved in producing this volume. We hope that the final result is worth the wait and meaningfully contributes to realizing our goal of promoting an East-West dialogue between philosophy and engineering.

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Apology

We apologize for the five-year delay in getting this volume of proceedings published. There were initial uncertainties in distributing responsibilities, which were compounded by a determination to work extensively with authors—especially from China—to give their ideas and arguments an adequate English expression.

Formatting Note

In an increasingly globalized world of scholarship, it is unfortunate that Chinese is so often forced into the straightjacket of Western orthographic conventions. To begin to redress this colonialist heritage, we have made a modest effort to respect and integrate Chinese conventions. For instance, Chinese proper names are given in Chinese form, family name first. This is only fair, since the Chinese do not force Western scholars to conform to Chinese conventions. To avoid any confusions that might arise, in the case of contributing authors, all family names, whether Chinese or not, are fully capitalized, except within the text of a contribution. In the table of contents, Chinese names are also given in Chinese. Additionally, many titles of books are given first in Chinese characters, then in *hanyu pinyin*, and finally in translation. *Pinyin* alone is really insufficient; Chinese is written with *hanzi* not in *pinyin*, which is only a teaching aid. Finally, when useful to substantiating an argument, Chinese characters are integrated into the main body of a text. Such adaptations are but small first steps in establishing a mutually respectful bridge in scholarship between East and West.

We wish to thank our editors at Springer and the Boston Studies in the Philosophy and History of Science for going to the extra work entailed in this process.

Acknowledgments

We wish to acknowledge and thank, first and foremost, the University of Chinese Academy of Sciences for its financial support of the Forum on Philosophy, Engineering, and Technology that took place in Beijing, China, November 2–4, 2012, and for editorial assistance through a professional development fund at the Colorado School of Mines, as well an anonymous donor.

Senior editor Carl Mitcham also wishes to thank colleagues in the School of Philosophy, Renmin University of China, especially Dean Yao Xinzhong and Professor Liu Yongmou, for their hospitality during the time when much of his work on this book was being done.

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Introduction: Intensifying Encounters

Carl MITCHAM

Abstract This introductory overview suggests ways that the collection of 25 articles and interviews encourages encounters between East and West across a spectrum of issues related to the philosophy of engineering broadly construed. It begins by calling attention to the background work of Joseph Needham and John Dewey and then briefly considers how individual chapters approach histories, cultural attitudes, social and political factors, and educational, industrial, and other issues as related to the philosophy of engineering. In so doing, it promotes a thesis of Li Bocong that the philosophy of engineering without history is empty and the history of engineering without philosophy is blind. The texts provide a range of entrance points, including perspectives from engineers and philosophers, historians and anthropologists, theory and practice, and science and technology. The volume concludes with extended interviews with leading Chinese contributors to philosophical engagement with technology, Yuan Deyu and Liu Dachun. Overall the hope is to enhance philosophical approaches to engineering in both China and the West.

Introduction

The unifying theme of this collection is an effort to intensify a twofold encounter: between engineering and philosophy and between China and the West. In both cases, the work of Joseph Needham provides useful background. While referenced in two of the chapters that follow (those by Wang Nan and Wim Ravesteijn), a brief analysis of his and his colleagues' achievement may further inform our project.

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Joseph Needham: Science, Technology, and Philosophy

In the apt phrase of biographer Simon Winchester (2008), Li Yuese (to use his Chinese name) was "the man who loved China." But he did not start out that way. Needham was deeply a man of the West—the kind of eccentric genius often viewed as an archetypical expression of British academic culture.

Needham was born in 1900 as the only child of a musician mother and medical doctor father. He originally planned to follow in his father's footsteps, but during his studies at Cambridge, he switched to biochemistry and earned a doctorate at age 25, specializing in embryology and morphogenesis.

Unlike many scientists, from the beginning Needham wrote with vigor, clarity, and ease and sought to articulate general ideas animating his particular research commitments. His first three books were more on philosophy than science. *Science, Religion and Reality* (1925) was an edited volume arguing compatibilities. *Man a Machine* (1927) was a polemical pamphlet reply to Eugenio Rignano's vitalist argument in *Man Not a Machine* (1926). *The Skeptical Biologist* (1929) was a more substantial defense of the emerging program in biochemistry. In a favorable review, philosopher C.E.M Joad complemented Needham for his measured praise of biological abstractions and recognition of their limitations. As Joad summarized Needham's view, "Science is capable of dealing with everything; but it is not capable of telling us the whole truth about anything" (Joad 1930, p. 755). In Needham's own words, "The mechanical theory of the world, necessary as it is, cannot any longer be considered to involve the exclusion of all other theories of the world; or put in another way, it is a theory of the world, and not, as the last century wished to regard it, a pocket edition of the world itself" (quoted in Joad 1930, p. 756). Long before the criticisms of science and technology studies scholars in the 1970s (with many of whom he would eventually engage), Needham saw modern science, however valuable, as limited—a judgment that no doubt left him open to appreciate the quite different tradition of Chinese science.

His first major work, a three-volume *Chemical Embryology* (1931), further revealed a fascination with history. Beyond analyzing embryological development, it surveyed development in the field itself, from ancient Egypt to the present, with references from a multitude of European languages in which Needham was fluent. A review in *Nature* described it as "a classical book" insofar as it defined and consolidated the field (H. 1932, p. 183); another review in *The Lancet* proclaimed the "over 2,000 pages in these three volumes [is an] erudite work of exceptional merit" and "a great work" (Anonymous 1932, p. 86); an essay review in *Science Progress* judged it to be "of immense value" (Pantin 1932, p. 334). So popular was the historical material that it was shortly published separately as *A History of Embryology* (1934). Looking back a mere decade, a reviewer already called it a "monumental work" (Grüneberg 1943, p. 134). Reconsidering the publication six decades on, another reviewer continued to judge it as a classic but mildly lamented how "having started so outstandingly in natural sciences [Needham] slowly drifted 'eastward' focusing his interests more and more on the history of China" (Schröder 1992, p. 94).

The immediate future, however, saw Needham continuing his effort to harmonize science and the humanities. Five years later, he delivered the Terry Lectures at Yale on *Order and Life*, dedicated "not [to] the promotion of scientific investigation and discovery, but rather the assimilation and interpretation of that which has been or shall be hereafter discovered, and its application to human welfare, especially by building the truths of science and philosophy into the structure of a broadened and purified religion" (Needham 1936, p. 1).

Then in 1942 there appeared a second major work on *Biochemistry and Morphogenesis*, restating and extending *Chemical Embryology*. Medical journals called attention to its practical value, as in the *British Medical Journal* (Anonymous 1943a), *New England Journal of Medicine* (Anonymous 1943b), and *Psychosomatic Medicine* (Gerard 1943). Other reviewers praised Needham's work as of "vast general significance" for cancer research (Haddow 1943, p. 494), for its relevance to genetics (Grüneberg 1943), as "a scholarly achievement" in biology (Stone 1943, p. 766), and as "one of the most stimulating books in the current biological literature" (Hamburger 1943, p. 268). In regard to the history of science, a reviewer expressed "astonishment at the breadth and detail of the author's learning" (Edsall 1934, p. 525). A general intellectual comment also judged it as "memorable at once for its breadth of learning and of view" (Sherrington 1943, p. 262). A few years later, a scientific review concluded it would "go down in the history of science as Joseph Needham's *magnum opus*" (Mayer 1949, p. 202). Needham's work in biochemistry seemed destined to be his major life project, with which he would be permanently identified—without any indication of the project that would in fact become his defining achievement: *Science and Civilisation in China*.

Needham's conception of what was then the new field of biochemistry, which in two decades would feed into molecular biology, was both an intellectual knowledge-producing program and at least implicitly a technological one. Chemical embryology was pursued not just to understand nature but to enable humans to more effectively manipulate their own physiological formation and deal with occasional aberrations. This was all the more the case because, as Needham argued, scientific knowledge offered no more than a partial insight into reality. To quote again from *The Skeptical Biologist*: "Science is capable of dealing with everything; but it is not capable of telling us the whole truth about anything." That science provides only a partial truth about anything leaves the knowledge it produces, insofar as possible, open to being used for everything. There is no substantive reality to be respected or loved; every scientific object is there to be manipulated by scientific technology.

It was thus natural that when Needham subsequently sought a concrete way to exhibit the great achievements of Chinese science, he created a list of discoveries and inventions spanning two thousand years to demonstrate its reality. This list includes such contributions to scientific knowledge as an algorithm for extracting square and cube roots, the proper motion of the stars, geological erosion and sedimentation, and the circulation of blood, along with hundreds of technological creations that go well beyond Francis Bacon's paean to the historical importance of printing, gunpowder, and the compass to include a host of instruments of mundane utility such as the abacus, calipers, toothbrush, and wheelbarrow (see Needham

1993). Needham saw as elements in a synthetic whole what other scholars might distinguish separately as science and technology. For Needham, science includes technology. In further illustration of his perspective, *Science and Civilisation in China*, volume 4, is titled "Physics and Physical Technology," with Part 2 being devoted to "Mechanical Engineering." Volume 5 is on "Chemistry and Chemical Technology." And in a popular exposition analyzing "Poverties and Triumphs of the Chinese Scientific Tradition," Needham identified "scientists, engineers, and artisans" as the common bearers of this unified technoscientific tradition (Needham 1963, p.11).

During his formative years, Needham not only became a world-renowned biochemist but also a lifelong radical Christian socialist, one with strong sympathies for Marxism. Technoscience was to be pursued, as Bacon himself had argued, in Christian charity—a view that Karl Marx secularized and revolutionized. And although originating in Europe, technoscience was conceived as a common patrimony of humanity in ways that would blend into his understanding and affirmation of the technological utility of modern science.

In 1937, in the midst of his expanding achievements in biochemistry, Needham met and began a long-term affair (accepted by his wife Dorothy) with Lu Gwei-djen, a graduate student from Shanghai. Recall that this was the year World War II began in earnest in Asia. Japan had invaded Manchuria in 1931 and then, after consolidating its rule there, in 1937 moved south to attack Beijing (July) and Shanghai (August) and begin the Nanjing Massacre (December). It was Japan that initiated indiscriminate aerial bombing of civilians in Shanghai, causing Jiang Jieshi (Chiang Kai-shek) to make an alliance with Mao Zedong and the Chinese communists, whom he had persistently pursued throughout the Long March retreat of the Red Army to Yan'an in Shaanxi Province—from where Mao would lead the Communist Party to victory after 1945. Just as the Soviet Union bore the brunt of the German *Wehrmacht,* it was China that suffered most and inflicted the greatest damage on the Japanese Imperial army. World War II began and ended in Asia, not in Europe. And it was in this historical context that Needham fell in love not just with Lu Gwei-djen but, through her, with China and all things Chinese. He immediately began to learn the language and started lobbying the British government to support China against the Japanese.

Under the auspices of the Royal Society—to which he had been elected a fellow in 1941—Needham became director of the Sino-British Science Co-operation Office and in 1942 made his first trip to China, visiting the war capital of Chongqing with technical supplies for Chinese scientists working there in their universities in exile. His longest trip in late 1943 terminated in Gansu at the Dunhuang Caves near the end of the Great Wall and a traditional Silk Road border post. Everywhere he went he purchased or was given historical and scientific artifacts that he shipped back to Cambridge and which served eventually as a resource for subsequent research at what has become the Needham Research Institute.

After the war, from 1946 to 1948, Needham became the first head of the Natural Sciences Section of the new United Nations Educational, Scientific and Cultural Organization (UNESCO) in Paris. In fact, he was the person who insisted to Julian Huxley, the first UNESCO director, that science be part of what was originally to be just an educational and cultural organization. It was Needham who put the S in UNESCO, arguing that science was the basis for a universal culture and developing what became known as the "periphery principle": an obligation of the more scientifically active countries to share their knowledge and resources with scientifically developing or disadvantaged countries (Petitjean 2006). When, in his 1949 inaugural speech, US President Harry Truman appropriated scientific and technological development for an anti-Communist ideology, Needham—who had become a defender of the new People's Republic of China (PRC), which was established that same year—became even more at odds with American policy than previously. In his return to Cambridge, he devoted the rest of his life, until his death in 1995, to writing and publishing with numerous Chinese colleagues the expanding series of contributions to *Science and Civilisation in China*.

John Dewey: Complementing Needham

Needham's expansive view of science is one shared by the American pragmatist tradition, especially in the work of John Dewey. As such, Dewey provides a complementary background, since he spent more time in China (1919–1921) than any other country than the United States. As Dewey argued in the last book he published before undertaking his more than two-year sojourn in China:

> Science is experience becoming rational. The effect of science is thus to change men's idea of the nature and inherent possibilities of experience…. Instead of being something beyond experience, remote, aloof, concerned with a sublime region that has nothing to do with experienced facts of life, it is found indigenous in experience:—the factor by which past experiences are purified and rendered into tools for discovery and advance. (Dewey 1916, p. 225)

Dewey's residency in China occurred at the height of the New Culture Movement, which broke out on May 4, 1919, in student protests against the Treaty of Versailles failing to return German colonial territory in Shandong Province to Chinese sovereignty, awarding it instead to Japan. China had been persuaded to send troops to France to fight with the Allies, on the promise that once Germany was defeated, China would recover German-occupied territory. When the Treaty of Versailles instead conveyed the German concessions to Japan, students revolted. The result was that although China had declared war on Germany, it never signed the treaty ending the war.

Dewey had arrived in Beijing on May 1, 1919, and for the next two years made an effort to help Chinese students and intellectuals reflect pragmatically on the problems China faced. As Jessica Ching-Sze Wang writes in her study of *Dewey in China*:

> Dewey's response to the May Fourth movement was more than enthusiastic; the social energies being released galvanized him. As Dewey wrote to his children in June 1919, "never in our lives had we begun to learn as much as in the last four months. And the last month particularly, there has been too much food to be digestible." Indeed, the May Fourth movement was China's gift to Dewey. It kept him excited, involved, puzzled, and, at times, frustrated. (Wang 2007, p. 5)

In the broad criticism of Confucianism that cultural movement figures of the time, such as Lu Xun and Hu Shih, leveled at "Mr. Confucius," Dewey represented the alternative of "Mr. Democracy" and "Mr. Science." Certainly for Dewey, science and democracy went together, but Dewey was cautious about any quick and easy Chinese adoption of institutions that had gestated in the West over a long historical period and continued to exhibit their own problems. As Dewey argued in his first major post-China book, *The Public and Its Problems* (1927), democracy should not be equated in any simple way with universal suffrage and "one-person one-vote" government. Democracy entails the public becoming more intelligent through the progressive exercise of a scientific, experiential understanding of the world and a corresponding technoscientific philosophical outlook.

Despite the central importance of engineering as an aspect of technology in any technoscientific philosophical outlook, in their quite different encounters with China, neither Needham nor Dewey ever thematized engineering as such. Without making any specific claims for the present collection, it can still be understood as making an effort to intensify the kind of encounters they exemplify. Indeed, no effort has been made to present the articles in some clearly defined analytic perspective. The Needham and Dewey backgrounds are offered simply as two contexts that remain alive today—in the continuing discussion of Needham's research program and in the contemporary exploration of, for instance, relationships between Confucianism and pragmatism—to which the 25 chapters in this volume can be conceived as making a modest contribution.

The chapters themselves are grouped into four sections: theoretical issues, practical issues, engineering history, and ethical issues. In each section, contributions are ordered simply alphabetically by author family name. By way of introduction, it is nevertheless useful to suggest some analytic relationships.

Philosophy of Engineering: Theoretical Issues

Grouping seven chapters together under the heading of theoretical issues and six more as practical issues is not meant to separate theory from practice but only to suggest a modest division of labor in which some arguments are more general and stage setting for the intensification of encounters between engineering and philosophy, East and West. Within this first group, one of the more important is Wang Nan's "Ancient Chinese Attitudes toward Technics." This chapter provides the kind of historico-philosophical background required by any Western thinker who aims seriously to consider Chinese thinking about technoscience. Her astute overview references classic texts from the early period of the Zhou dynasty (going back to the second millennium BCE), along with Confucian and Daoist thinking, and then the *Kaogongji* (from the Spring and Autumn Period) and *Tiangongkaiwu* (from the end of the Ming Dynasty). In the process, she identifies three ideas that distinguish Chinese thinking: a sense of the material world as self-subsisting, the primacy of practical or political affairs in human life, and a concern for harmony between human beings and the larger world in which we all live.

Complementing Wang Nan in significance is Li Bocong's "On Relationships Between the History and Philosophy of Engineering," which offers a programmatic argument for integrating history and philosophy into the philosophy of engineering. The relationship between history and philosophy here is compared to that which has emerged since the work of Thomas Kuhn in the philosophy of science. To some degree, the present volume as a whole is an attempt to apply Kuhn's principle to the understanding of engineering, arguing that "philosophy of engineering without history of engineering is empty; history of engineering without philosophy of engineering is blind."

Together with Wang Nan and Li Bocong, other contributors in the theory section consider what philosophy can learn from engineering (Diane Michelfelder), the philosophical understanding of the new world of reality created by engineering (Hans Poser), and what philosophical analysis can contribute to technical understandings within engineering (Wang Guoyu et al.). Michelfelder's "Critical Thinking and Heuristics" makes a strong case for philosophers, especially philosophy teachers, learning something from the practices of reflective engineering and engineering education. The teaching of critical thinking, as a key element in philosophy curricula, has been developed by professional engineering communities so that it now plays an increasingly central role in the formation of future engineers. This approach, which emphasizes heuristics, can be useful not only to engineers.

Poser's "Ontology of Technical Artifacts" adopts a quite different approach, attempting to bring philosophy to bear on understanding our increasingly engineered world. His argument begins by reviewing the ontologies of Aristotle and Kant, insofar as these may have implications for an engineering ontology. He then proceeds to consider the dual nature analysis developed by Peter Kroes and argues for expanding it to take into account causality, creativity, intentionality, and finality. This new proposal draws on the work of Karl Popper and especially Nicolai Hartmann. This chapter has more explicit references to different philosophical theories than any other in the theory section.

Philosophers Wang Guoyu, Li Lei, and Cao Xu, in "Feasibility and Acceptability in Engineering," illustrate still another approach to the engineering-philosophy relationship by using the tools of philosophy to question and refine engineering concepts. In the process, they argue the necessity of incorporating what they term "acceptability studies" into engineering feasibility studies. They admit that, from the perspective of socio-technical systems, feasibility also connotes acceptability but maintain that a broader sense of feasibility goes beyond simple acceptance to entail a synthesis of facts and opinions, along with problem-solving procedures that engage democratic negotiations.

Wang Dazhou's "Toward an Experimental Philosophy of Engineering" picks up and expands on some of the ideas of John Dewey that were mentioned above. Along with Dewey, he rejects the idea that modern technology and engineering degrade human beings, limit their freedom, and threaten the contemporary democratic order. Like Dewey, Wang Dazhou argues for approaching the question of technology and engineering through an experimental philosophy that views both engineering and human nature from the perspective of evolution. The basic challenge for humanizing engineering is responding positively to questions about what kind of people we want to become through the development and use of our technology.

This section appropriately concludes by giving engineer Yin Ruiyu the last word. In "From Engineering to the Philosophy of Engineering," he argues that philosophy and engineering are two indispensable basic activities in modern society, with philosophy of engineering as a bridge connecting them. A "triism" of science, technology, and engineering is the foundation of the philosophy of engineering. Engineering thinking matters to engineers and is different from general theoretical thinking. Construction, design, and practice in engineering manifest practical reason. Engineering should be aimed at public service, and the public should understand and take part in engineering. Engineering has a direct relationship on the public interest and social welfare.

Philosophy of Engineering: Practical Issues

As noted above, the difference between theory and practice here is not to be a strong bifurcation but simply one of generality. The six chapters grouped under practical issues are slightly more related to engineering conduct than those in the theory section, except perhaps for that by Yin Ruiyu. Indeed, the chapters in this section may be thought of as further exemplifying Yin's approach; certainly there are more engineers included in this group than in others in the volume. Nevertheless, the accident of alphabetical order places two general arguments in a lead-off position.

Eric Aslaksen's "An Engineer's Approach to the Philosophy of Engineering" presents the views of a practicing engineer on two questions germane to any philosophy of engineering. One is the relationship between engineering and society; another is the design process. In the design process and the movement from functional specifications to physical realization, Aslaksen identifies further issues calling for philosophical attention. He includes specific reference to a philosophy of engineering research program on technical functions pursued in the Netherlands under the leadership of Peter Kroes, which was part of a larger movement called the "empirical turn." In this regard, it is worth referencing a retrospective self-assessment of this Dutch research program (Franssen et al. 2016).

Bristol's "The Philosophy of Engineering and the Engineering Worldview" again draws heavily on Dewey. Dewey's philosophy of science was grounded in an interpretation of science as extended practical inquiry. Bristol argues for adapting this view of science to engineering and for interpreting engineering as a form of inquiry oriented toward making sense of what we do and how we do it. Insofar as this is the case, engineering actually constitutes a world view that encompasses and supersedes the scientific world view.

Unlike the chapters by Aslaksen and Bristol, "A Biomimetic Approach to Complex Global Problems" is authored by a team: James Barnes, Susan Barnes, and Michael Dyrenfurth, two of whom are engineering technology professionals. Their argument is that responding to complex global problems will require different ways of thinking than the technoscientific practices of the past that sometimes gave rise to problems. Slightly rephrasing their argument, although it is common to argue for interdisciplinarity in what could be called first-order engineering practice (the design of processes and products to meet limited needs), second-order engineering to address problems that emerge in the form of unintended consequences will involve new forms of interdisciplinarity. Their proposal for this new form of interdisciplinarity is engineering pursued not against but in symbiosis with nature through the new field of biomimetics. Biomimetic engineering design has the potential to enhance the management of major complex global problems.

Donald Hector, Carleton Christensen, and Jim Petrie are a second engineering-based team working on "Toward a Practical Philosophy of Engineering" that would identify limitations in the profession and come to terms with complex, socioeconomic-technological problems. The issue of sustainability is the test case. Along with Bristol, these authors draw from developments in the philosophy of science, lessons for the philosophy of engineering. The idea that engineering is a values-free discipline is as outmoded as the conception of science as value neutral. For engineering to retain its relevance as a profession, it must incorporate this insight. To address such highly complex problems as sustainability, engineers need to see themselves as a part of the world in which problems arise, not as separate from it.

Still another analysis of the relationship between philosophy of science and philosophy of engineering is found in Viola Schiaffonati and Mario Verdicchio's "What Do Bridges and Software Tell Us about the Philosophy of Engineering?" Using specific engineering practices, the authors argue for recognizing that experimentation is science and in engineering takes different forms. Their chapter further makes one of the strongest links in this section between concrete engineering work and philosophical reflection.

In the last chapter of this section, another engineering-based team from Brazil—Édison Renato Silva, Domício Proença Jr., and Roberto Bartholo—reflects critically on three important engineer contributors to the philosophy of engineering in "Herbert Simon Meets Billy Vaughn Koen and Joan van Aken." American cognitive scientist Simon's theory of the unity of design activities is tested against the ideas of American nuclear engineer Koen and Dutch business administration researcher van Aken. The result questions the understanding of engineering as applied science, engineering as one of many sciences of the artificial, and advancements in science as the source of engineering progress.

Philosophical Perspectives on Engineering History

This is the shortest section of the book. Nevertheless, these four chapters make an important contribution to the programmatic argument of Li Bocong, by placing history in the foreground of four historical case studies that incorporate philosophical perspectives and interests. Three of these studies are based in China. A fourth reaches outside of China into Indonesia, another key country in Asia.

The chapter on "Characteristics and Status of Early Chinese Engineering Education" by Chen Jia and Wang Jian examines one of the earliest engineering education institutions in China, the Fuzhou Shipbuilding School. Adapting the approach of cultural anthropology, the authors describe the status, key characteristics, and impact of engineering education during the late 1800s movement to westernize in China. The Fuzhou school idea that engineering education needed to incorporate engineering practice has had significant influence on subsequent Chinese engineering curricula.

Fang Yibing and Qian Wei's "The Earliest Western-Trained Engineers in China's Iron and Steel Engineering Industry" offers a second case study of engineering education focused this time on the Hanyang Iron Works, which became the Hanyehping Coal and Iron Limited Company. To develop indigenous expertise, in the early 1900s, the firm sent Chinese students to Western countries to study metallurgy. This chapter recounts some of the foreign study experiences of these engineers and their subsequent working lives in China and provides insight into how the modern Chinese iron and steel industry was established. (An appendix includes a historical document by a western educated Chinese engineer who contributed to this establishment.)

Still a third Chinese case study is Wang Bin's "Conflicts and Adaptations in Technology Transfer to Modern China," focusing this time on the German colonialist construction of the Kiaoji Railway in Shandong Province. The account details conflicts based on cultural factors and economic interests and how local authorities worked against German attitudes to resolve conflicts. The conflicts and adaptations illustrate interactions between two parties during a particular technology transfer in the context of colonization.

Complementing the three case studies of Chinese initiative—by an educational institution, a corporation, and local politicians—historian Suzanne Moon's "Engineering and the Postcolonial" offers a broader historico-philosophical argument. Using the case of Indonesia, Moon explores how postcolonial memories have influenced attitudes toward technology and engineering and therefore the technological values and identities of both engineers and the postcolonial cultures. Paying attention to deeper histories and questioning the practice of silencing are ways that engineers might strengthen their ability to analyze technology-related conflicts and enhance their relationships with broader publics.

Engineering, Ethics, and Society

Section four turns to the aspect of practice that has received the most sustained attention in the philosophy of engineering broadly construed. Philosophy of engineering as philosophy involves epistemology, metaphysics, ethics, political theory, aesthetics, and more. But any description of this regionalization of philosophy will easily note the predominance of ethics. The six chapters in this section reflect that prominence.

Rita Armstrong's "Between Optimism and Despair" again brings anthropology into the mix to examine three cases of what has sometimes been called humanitarian engineering: introducing new cook stoves into Sri Lanka and Bangladesh and biomass generation of electricity in Sri Lanka. Typically engineers are optimistic about technological development, while anthropologists are skeptical. Engineers see benefits, whereas anthropologists see the difficulties of technology transfer and its often socially disruptive effects. But Armstrong's case studies reveal the emergence of more nuanced attitudes that acknowledge problems caused by power differentials between development agencies and communities and approach deep-seated structures of inequality with interdisciplinary cooperation.

Social scientists Christelle Didier and Patrick Simonnin report on the situation in France, where it is common for a student to say, "I became an engineer by accident." Engineering attracts students as a path to a rewarding career, but many wind up on this path without much awareness of how they got there or what it will require. Studying the associated socialization process from the engineering students' point of view aims to better understand the construction of an engineering culture and ethos in one advanced Western country, France.

In "Chinese Student Perceptions of Engineering Ethics," Heinz Luegenbiehl empirically examines an aspect of engineering socialization in the East. On the basis of his own experience teaching at an engineering school in China, Luegenbiehl reports on and analyzes a survey of what a subset of Asian engineering students think about a set of topics commonly focused on in engineering ethics in the West.

"Engineering Policy" by Carl Mitcham (with an appendix on key Chinese terms added with Zhang Kang) shifts from individual or personal ethics to consider an under-examined aspect of what Joseph Herkert (2001) and others have termed macro-ethics. Once again a comparison is made between thinking about science and thinking about engineering, by suggesting that the common distinction between science for policy and policy for science can be adapted to understanding relationships between engineering and policy. Engineering for policy involves engineers advising politicians on what types of engineering work could be done to achieve policy goals. Policy for engineering focuses on how much to promote engineering education or to encourage high standards in engineering construction and ethics.

Wim Ravesteijn's "The Dao of Chinese Water Management and Development" offers a Western assessment of a Chinese cultural perspective that can influence engineering practice. Comparing current Integrated Water Resources Management from twentieth-century Netherlands with historical Chinese approaches suggests possible engineering policy perspectives that can bridge East and West.

The last chapter in this section, Sun Lie's "Decision Making in the 120MN Shanghai Forging Hydraulic Press Project," provides a final case study of the tensions between politics and engineering in China. This project, which originated in the early years of the PRC, required its chief engineer to carefully negotiate political demands and engineering feasibilities. Its success is a testament to a particular type of ethical engineering leadership that is probably not unique to China.

These six chapters on engineers, ethics, and society are among the most diverse in the collection. They consider both micro- and macro-ethical issues with reference to perspectives or experiences from Australia, Bangladesh, China, France, the Netherlands, Sri Lanka, and the United States.

Supplementary Interviews

The two final chapters are unique documents illuminating development of philosophical reflection on technology in China. The first interview is with engineer Yuan Deyu, who worked at technological institutions in northeastern China; the second is with philosopher Liu Dachun from the humanities faculty at Renmin (People's) University of China in Beijing. The works of these two scholars have exercised important influences on the emergence of the philosophy of technology and engineering with Chinese characteristics.

Yuan Deyu was an initiator of what Yuan himself (adapting a distinction that he attributes to Mitcham 1999) calls Chinese engineering philosophy of technology. The interview includes reference to his close collaboration with Chen Changshu, whom Wang Nan (2015) has identified as another founder of contemporary Chinese philosophy of technology and with whom an English interview is also available in a separate publication (Chen Changshu and Wang Qian 2015). Their initiatives can be traced back to the Great Leap Forward where, despite being a human and economic disaster, demands to learn from workers actually led to modest technological innovations. During the Cultural Revolution, another socially destructive period, engineering reflection on technology took the form of case studies that were subsequently generalized in a framework provided by Japanese scholarship on the theory of technology. Against this background, Yuan questions many of the ways Chinese philosophers have tried to adapt or relate to Western studies in philosophy and technology.

Liu Dachun is a leader in what has been called "humanities philosophy of technology." He too recounts experiences during the Cultural Revolution and their formative influence on his scholarly work. Here he recalls his initial education in science, his perseverance during hard times, the solaces of literature, and his scholarly work at Renmin University, where he contributed in important ways to bringing Western philosophy of science and technology into the Marxist study of dialectics of nature. He further reflects from the Chinese context on relationships between science, technology, engineering, and industry and identifies four science policy challenges in the PRC: problematics of centralized, state-run research funding, academic freedom, relationships between knowledge and power, and technoscience as both private versus public goods.

The complementary historico-philosophical reflections in these two chapters will be especially useful for anyone interested in the development of the philosophy of technology and engineering in China. The overlapping analyses of the dialectics of nature, for example, can help Western thinkers better appreciate an often misunderstood but pertinent field of discourse.

Conclusion

The collection as a whole closes with a brief comment by Paul Durbin, one of the American philosophical founders of the philosophy of technology and engineering.

No single book can cover all the bases for intensifying encounters between philosophy and engineering, East and West. The references to Needham and Dewey at the beginning of this introduction deserves to be complemented with the extensive work that has continued at the Needham Research Institute, at the Institute for the History of Natural Science of the Chinese Academy of Sciences, and at numerous other organizations and among individual scholars, East and West. Taken together, the 25 chapters of the present collection aspire to make a modest contribution in this multiplicity of efforts, emphasizing the benefits of collaborations focused on philosophy and engineering.

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Part I

Philosophy of Engineering: Theoretical Issues

Chapter 1
On Relationships between the History and Philosophy of Engineering

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Abstract The relationship between the history and philosophy of engineering is similar to that between the history and philosophy of science and that between the history and philosophy of technology. Lakatos' thesis—that "philosophy of science without history of science is empty; history of science without philosophy of science is blind"—applies as well to the history and philosophy of engineering. To advance the history of engineering requires some attention to the nature of engineering and vice versa. The effort here is to draw some lines of demarcation among the histories of engineering, of technology, of science, and of economics from a philosophical point view. With regard to history, a theory of engineering evolution can bridge philosophy and history; an important part of such an evolution will also consider historical developments in the engineering community. There nevertheless remain important tensions and complementarities between the history and philosophy of engineering.

1.1 Introduction

Following establishment of science and technology studies (STS), engineering studies (ES) emerged as another interdisciplinary field both in East and West. In 2003, the Center for the Study of Engineering and Society was established at the Graduate University of the Chinese Academy of Sciences. From 2004 to 2008 this center published four annual volumes of *Gongcheng yanjiu* [Engineering studies]; in 2009 this periodical began publishing on a quarterly basis. In 2004, the International Network for Engineering Studies (INES) was established at Paris and in 2009 began publishing the triquarterly journal *Engineering Studies*. The result was that two journals began publishing under the same name, one in Chinese and another in English, clearly attesting to the importance of ES as a new interdisciplinary field. Just as STS has involved collaborations among the philosophy, sociology,

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and history of science and technology, and other disciplines (Cutcliffe 2000), ES has likewise involved interactions among philosophy, sociology, and history of engineering, as well as other disciplines.

Indeed, as a contributor to ES, the first decade of the twenty-first century witnessed the rise of the philosophy of engineering as a new sub-discipline in philosophy. The period between 2002 and 2007 witnessed the publication of four books on the philosophy of engineering in China and in Europe:

- *Gongcheng zhexue yin lun* [Introduction to philosophy of engineering] (Li 2002)
- *Engineering Philosophy* (Bucciarelli 2003)
- *Gongcheng zhexue* [Philosophy of engineering] (Yin et al. 2007)
- *Philosophy in Engineering* (Christensen et al. 2007)

During roughly the same time frame conferences devoted to the philosophy of engineering began to take place in China, Europe, and the United States. Philosophy of engineering thus appears to have met two of four sociological criteria often used for identifying the establishment of a new academic discipline: academic books, journals, conferences, and programs.

The sociology of engineering has also begun to emerge as a sub-discipline. During the twentieth century a few articles with the terms "engineering" and "sociology" in their titles appeared in English, but it was not until the twenty-first century that a stand-alone volume appeared in China as *Gongcheng shehuixue dao lun: Gongcheng gongtongti yanjiu* [Introduction to sociology of engineering: Study on engineering community] (Li 2010b). This was followed in 2011 by an international workshop on engineering and sociology in Beijing, with participation by some 50 scholars from North America, Europe, South America, and China.

Since the task of ES is to advance research in historical, social, philosophical, political, and cultural studies of engineers and engineering, the emergence of the philosophy and sociology of engineering as two fledgling disciplines can be expected to be followed by emergence of the history of engineering. In fact, 2010 saw the creation of a project, sponsored by the Strategy Division of the Chinese Academy of Sciences, on the history of modern engineering in China. Although there have been a few books in English on the history of engineering, and the Chinese project aims to publish a series of volumes, the history of engineering nevertheless calls for examination of relationships between the history and philosophy of engineering.

1.2 Two Disciplines with a Common Fate

The history and philosophy of engineering share a common fate. As Don Ihde has observed, it was Hegel who began to do "philosophy of…". Although the preposition "of" does not occur in German, when translated into English Hegel's *Geschitesphilosophie* and *Religionsphilosophie* become "philosophy of history" and "philosophy of religion" (Ihde 1993). Following Hegel many "philosophies of …" have been created. As a younger sibling of the philosophy of science and the philosophy of technology, the philosophy of engineering has now entered the "philosophy of …" family.

There is also a "history of …" family that parallels the "philosophy of …" family. The "history of …" family includes the history of science, of letters, economic history, and so on. In these two families, the history of science is a cousin to the philosophy of science; similarly, the history of technology is a cousin to the philosophy of technology. While both history of science and history of technology have become accepted disciplines, the history of engineering remains to be fully developed.

There have been a few publications in the history of engineering. Despite H.G. Armytage's *A Social History of Engineering* (Armytage 1961) and some other specialized historical studies of engineering, often by STS scholars, historians have largely neglected engineering as a field. "History of engineering" is not included as an index topic in *Technology and Culture*, international journal of the Society for the History of Technology (SHOT). In 1974, at his SHOT presidential address on "Engineers are People", John B. Rae began by declaring, "The proper way to introduce this topic is to announce that the engineer is a neglected figure in history and that I propose to remedy this defect" (1975, p. 404). Yet more than a decade later, as noted by Steven Goldman (1990), Cecelia Tichi's *Shifting Gears* (Tichi 1987, p. 98) could still refer to the engineer "the invisible man of [academic] American studies". Gary Downey, Arthur Donovan, and Timothy J. Elliott (Downey et al. 1989), likewise, in an assessment of STS, referred to "the invisible engineer." Up through 2002, when it ceased to be published in *Technology and Culture*, the annual "Current Bibliography in the History of Technology" failed to include "history of engineering" as an independent classification. However, an article entitled "Making the Invisible Engineer Visible" (Johnston 2011) was published in *Technology and Culture* in 2011, which affords much food for reflection and can even be regarded as a sign of trying to study to some degree the history of engineering.

Engineering is also under-represented in philosophy. Steven Goldman's "Philosophy, Engineering, and Western Culture" (Goldman 1990) and "The Social Captivity of Engineering" (Goldman 1991) called attention to a strong prejudice against engineering in the West. As Goldman wrote, "philosophy of science is [now] a fully accepted and highly respected branch of philosophy, while philosophy of engineering carries as much professional distinction as philosophy of parapsychology" (Goldman 1990, p. 140). However, as noted above, since the 1990s the philosophy of engineering has begun to be recognized as a field of research, and we can project that the same will occur with the history of engineering.

1.3 The Lakatos Thesis

With regard to the relationship between "philosophy of engineering" and "history of engineering", consider Imre Lakatos' well-known paraphrase of Immanuel Kant: "Philosophy of science without history of science is empty; history of science without philosophy of science is blind" (Lakatos 1970, p. 91). Lakatos' thesis is both descriptive and normative, and can be applied to the philosophy and history of technology, as well as to the philosophy and history of engineering. According to Lakatos, the combination of philosophical and historical research constitutes the most important factor for success in the philosophy of science.

Philosophers of science Thomas Kuhn, Imre Lakatos, and Paul Feyerabend all attempt to apply Lakatos' thesis. Kuhn, for instance, is known both as a historian and philosopher of science. His collection of papers from 1959 through 1976 (Kuhn 1977) includes both historiographic and "metahistorical" (or philosophical) studies. And in *The Road since Structure* he wrote that

> Though most of my career has been devoted to history of science, I began as a theoretical physicist with a strong avocational interest in philosophy and almost none in history. Philosophical goals prompted my move to history; it's to philosophy that I've gone back in the last ten or fifteen years; and it's as a philosopher that I speak this afternoon. … What we mostly thought we were doing as we turned to history was building a philosophy of science on observations of scientific life, the historical record providing our data. (Kuhn 2000, pp. 106–107)

Feyerbend's criticism of the separation of philosophy of science from its history is similar to Lakatos'. In "Philosophy of Science: A Subject with a Great Past", Feyerabend criticized much contemporary philosophy of science as "castles in the air" because of its dissociation from history.

> What we must do is to replace the beautiful but useless formal castles in the air by a detailed study of primary sources in the history of science. That is the material to analyzed, and this the material from which philosophical problems should arise. This is the material to be analyzed, and this is the material from which philosophical problems should arise. (Feyerabend 1999, p. 183)

This combination of philosophy and history is important not only for philosophers but also for historians. American historian of technology Melvin Kranzberg, one of the founders SHOT, in his 1985 presidential address, put forward a set of six eponymous laws. From the first ("Technology is neither good nor bad; nor is it neutral") to the sixth ("Technology is a very human activity—and so is the history of technology") they display a philosophical leaning that echoes Lakatos (Kranzberg 1986).

A SHOT symposium on philosophy of technology attended by philosophers Joseph Agassi (1966), Mario Bunge (1966), and Henryk Skolimowski (1966) saw their essays published in a special *Technology and Culture* symposium. Carl Mitcham and Robert Mackey's pioneering *Bibliography of the Philosophy of Technology* (1973) was also published as a special supplement to *Technology and Culture*. Both SHOT publications played important roles in the emergence of philosophy of technology as an academic discipline.

Chinese philosophers of engineering have conducted their own studies of the history of engineering, realizing that without of a historical basis, their own work would be no more than "castles in the air". Three activities that have advanced the history of engineering in China are the study of engineering evolution as a bridge between the philosophy and history of engineering, two workshops on the history of engineering attended by both historians and philosophers, and research on the history of modern engineering in China as an academic program (as mentioned in section one above).

From the beginning, the philosophy and history of engineering needed to support each other. At the same time, some distinguishing of these disciplines is required so that their collaboration can take place in a well ordered manner.

1.4 Distinguishing Histories

It was Karl Popper who raised the demarcation problem in order to distinguish science and metaphysics. Demarcation is needed as well when engaging with the four sub-disciplines in the field of history: those of science, technology, engineering, and economy. These sub-disciplines are interconnected, making separating any one completely from the other three impossible. However, that does not mean that any one should be confused with or reduced to another. How then can be demarcated?

It is relatively easy to draw a line of demarcation between the histories of science and of technology. Though connected, each has its distinctive object and essence. Generally speaking, the main object or content of the history of science is the sequence of scientific discoveries, while the main object or content of the history of technology is the sequence of technological inventions. Differences among the histories of engineering, technology, and economics are more difficult to draw.

Why and how can we distinguish the history of engineering from that of technology? The answer lies in the difference between the two types of activity. Engineering involves both technological and non-technological factors, with non-technological factors often playing a more important role. Lakatos divided history into two types: internal and external. There is no doubt that non-technological factors are involved in both technology and engineering. However, non-technical factors belong to external histories of technology, while technological factors belong to internal histories of engineering.

There are also differences between the history of engineering and economic history. Of the many non-technological factors involved in engineering activity, economics is often one of the most important, so that the history of engineering is necessarily associated with economic history. But economic activity and engineering activity may still be distinguished.

In *Capital* Karl Marx distinguishes two kinds of value: use-value and exchange-value. There are also two kinds of labor: abstract human labor and specialized human labor- power with a definite aim. For Marx, “As use-values, commodities are, above all, of different qualities, but as exchange-values they are merely different quantities, and consequently do not contain an atom of use-value” (*Kapital*, vol. 1, chapter 1, section 1). Additionally,

> On the one hand, all labor is, speaking physiologically, an expenditure of human labor-power, and in its character of identical abstract human labor, it creates and forms the value of commodities. On the other hand, all labor is the expenditure of human labor-power in a special form and with a definite aim, and in this, its character of concrete useful labor, it produces use-values. (*Kapital*, vol. 1, chapter 1, section 2)

Marx's view of the twofold character of the value of labor reveals the difference between engineering activity and economic activity, and therefore between the histories of the two. Engineering is a kind of activity that aims to create use-value by concrete useful labor, while economic activity is a kind of activity which means to create exchange-value by identical abstract human labor. Therefore, historians of engineering focus on the historical development of concrete useful labor and use-value, while economic historians focus on the historical development of abstract labor and exchange-value. From an economic perspective, all types of labor and engineering are homogeneous due to their nature as abstract labor and exchange-value, while from a point of view of engineering, different types of labor and engineering are heterogeneous, due to their nature as concrete labor and use-value.

It is the differences between two kinds of labor and two kinds of value that lead to the conclusion that the objects and contents of economics are different from the ones of engineering. In the field of economics, economists regard the exchange of commodities as an act characterized by a total abstraction from use-value, so they iron out the differences among concrete labor or distinct engineering. In the field of engineering activity, engineering practitioners regard their labor or engineering operation as an act itself characterized by a concrete creation and realization of use-value, so they embody and diversify the abstract labor in their engineering activity. In other words, the concrete labor and use-value that are abstracted and ironed out in the field of economics must return to the original condition or shape as concrete-engineering-themselves in the field of engineering.

Compared with scientific and technological activity, engineering activity is characterized more by social characteristics. For engineering activity, scale and scope are two important issues, while for scientific discoveries and technological inventions, the essence and nature lie in that which has been discovered or invented for the first time in history. For example railway, electronic, and communications engineering, the issues of scale and scope lie in the kernel of the field, which distinguish the engineering activity and history from scientific and technological activity, and their histories.

1.5 Engineering Evolution

The theory of engineering evolution involves both the philosophy and the history of engineering. On the one hand, because the theory of engineering evolution is a kind of general theory, philosophers have reason to regard it as philosophical. On the other, because in the field of history there are two kinds of historical works, theoretical and narrative, and the theory of engineering evolution is a kind of general theory about engineering development, some historians of engineering have reason to regard it as historical. The theory of engineering evolution thus bridges the philosophy and history of engineering.

One example of the relevant bridging can be found in the changing title of George Basalla's *The Evolution of Technology* (1988). When translated into Chinese, its title became *Jìshu fazhan jian shi* [Technology development short history]. Another example is *Engineering in Time: The Systematics of Engineering History and its Contemporary Context* by A.A. Harms, B.W. Baetz, and R.R. Volti (2004), which is divided into three sections: "Introduction to Engineering," "History of Engineering," and "Contemporary Context of Engineering." The authors state their purpose is to depict the evolving history of a complex network-based progression while simultaneously highlighting the dynamics of relevance to engineering. In a similar manner, *Theory of Engineering Evolution* (Yin et al. 2011) is divided into two parts: theoretical issues and case studies. Theoretical issues deal with the relationship between the theory of engineering evolution and other disciplines, such as dynamic systems of engineering evolution, evolution of engineering elements, evolution of engineering systems, mechanisms of engineering evolution, evolution of engineering culture, and evolution of engineering versus the progress of civilization.

In biology, Darwinian evolution has been accepted as a general theory. However, the founders of evolutionary economics Richard R. Nelson and Sidney G. Winter (1982) have been criticized as adopting a Lamarckian position. As one commentator summarizes:

> Their evolutionary theory is Lamarckian in that acquired characteristics can be passed on, rather than in modern Darwinian biology where individual genes can alter only through mutation at birth and the inheritance of acquired characteristics is ruled out. Lamarckian theory applies particularly to society because our cultural evolution is based on learning, whereas our genetic structure has hardly changed. (McKelvey 1991, p. 131)

However, Nelson and Winter can also be interpreted in Darwinian terms insofar as many economic innovations are simply the result of random variations that are selected by market forces. The details of such debates need not be dealt with here (but see Jia 2012, pp. 59–71).

1.6 The Engineering Community

Many scholars regard engineering activity as what engineers do. This is misleading insofar as engineering is a collective activity carried out by many different engineering practitioners. It involves engineers, but also workers, managers, investors, and other stakeholders. There is no doubt that engineers are important members of the engineering community. However, other indispensable members of the engineering community are also necessarily integrated into the activity in cooperation with each other, making them an important part of engineering history.

In the field of history, some historians have paid attention to engineers, while ignoring relationships with other members of the engineering community. For instance, the relationship between engineers and workers changed considerably during the twentieth century, which profoundly influenced the advancement of engineering. In the early 1900s, scientific management and Fordism arose in the fields of engineering. *S*cientific management, as developed by Frederick Winslow Taylor, initially while at the Midvale Steel Works and then transferred to the Bethlehem Steel Company, was promoted in *The Principles of Scientific Management* (1911). Taylorism, as it came to be called, focused on analyzing and rationalizing work flows. Fordism emphasizes more standardization, mass production, and associated mass consumption.

Engineering knowledge production and sharing are related to and influenced by the division of labor. In the history of engineering, there are different principles of knowledge production and sharing. In pre-Fordist factories, both engineers and workers were knowledge creators and sharers. In Taylorist or Fordist companies, workers operated in workshops or assembly lines strictly following the directives of engineers, dramatically increasing productivity.

Taylorism spread quickly in the USA and Europe. *The Principles of Scientific Management* was translated into a dozen other languages within 3 years. In 1913, after graduating from University of Illinois and when studying at Texas A & M College for a master degree, Mu Ouchu (1876–1943) sought advice from Frederick Winslow Taylor and Frank Gilbreth and discussed issues of the principle of management with them earnestly. At the same time, Mu sought Taylor's permission to translate *The Principles of Scientific Management* into Chinese, which was published in 1916. After his return from abroad, Mu started three cotton mills in China and applied Taylor's theory to practices in his own company, which made him a famous entrepreneur (Gao 2007, pp. 270–274). Taylor's principles involved replacing rule-of-thumb work methods with methods based on a scientific analysis of tasks along with the training of workers rather than leaving them to train themselves, thereby initiating new principles of engineering knowledge creation and sharing. In this new program, workers were considered passive and their ability for knowledge creation neglected. Fordism is similar in this respect. As for merits of scientific management, managers, psychologists, philosophers and others have done considerable research, but there has been little discussion of the topic from a knowledge creating and sharing perspective.

However, the situation has changed since the formation of the post-Fordism mode of production in the 1970s, in which workers are once again included in knowledge creating and sharing processes. Post-Fordism emphasizes service industries and often involves more specialized production and information technologies (Liu 2010, pp. 10–18). Such changes in knowledge production and sharing are important aspects of the history of the engineering community.

1.7 Tensions and Complementarities

Since the history of engineering inspires philosophers of engineering, they must research not only metaphysics and epistemology, but also economic and political philosophy and axiology. In many cases problems of economic and political philosophy and axiology are even more important than those of metaphysics and epistemology.

There is no doubt that history of engineering cannot be replaced by its philosophy or vice versa. But neither can the two be fruitfully pursued in total independence of each other. Already in the late 1980s, in a *Festschrift* for historian of technology Kranzberg, philosopher of technology Paul T. Durbin outlined the tensions and complementarities in the relationship between the history and philosophy of technology. He concluded as follows:

> Historians of technology … ought to become more aware of their philosophical presuppositions…. [A]t the same time … philosophers of technology … ought to work harder at getting their facts straight and at being more honest about the relation between their theories and alleged factual support…. [The] history of technology and philosophy of technology complement one another—as Melvin Kranzberg has for so long wisely recognized. (Durbin 1989, p. 129)

The same can be said for the relationship between the history and philosophy of engineering.

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Chapter 2
Critical Thinking and Heuristics: What Philosophy Can Learn from Engineering about the Back of the Envelope

Diane P. MICHELFELDER

Abstract Who benefits when philosophers and engineers get involved in academic conversations with one another? Such conversations are often one-way streets, with philosophers offering conceptual tools, insights, and modes of inquiry that serve as contributions toward developing the philosophy of engineering and influencing practices of reflective engineering and engineering education. However, philosophers also stand to benefit from closer conversational contact with engineers, as it can bring helpful challenges not only with regard to some of philosophy's basic assumptions, but also with regard to its common classroom practices. In this paper I take a hard look at one of these practices: the teaching of critical thinking. Long a staple within the philosophy curriculum in the US, critical thinking has in recent years been taken by those in professional engineering communities to play an important role in the formation of future engineers. I suggest that the approach to critical thinking which would be most useful to engineers would be one that underscores the value of heuristics. Such an approach to teaching critical thinking within the context of philosophy, however, is not the norm; in fact, teaching materials associated with critical thinking tend to be deeply suspicious of heuristical reasoning. Philosophy can learn from engineering about the value of heuristical reasoning as a form of critical thinking; here is a case in point, I propose, where engineering knowledge can improve philosophical knowledge.

2.1 Introduction

Critical thinking, so the typical definition runs, can be seen as the "skill of correctly evaluating arguments made by others and composing good arguments of your own" (Rainbolt and Dwyer 2012, p. 5), or as "the systematic evaluation or

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formulation of beliefs, or statements, by rational standards" (Vaughn 2010, p. 4). As calls continue to grow for transforming engineering education in order to improve the capabilities of future engineers—particularly the capability for making positive and rapid social change within a world marked by unprecedented complexity and connectivity—the development of critical thinking skills is often seen as making a contribution toward this end. It is not difficult to see why. Such skills can play a strong supportive role in the development of a number of the components of the vision of the future engineer proposed by the National Academy of Engineering: someone with a strong analytical mind who is also able to synthesize knowledge from a variety of fields, who is talented both with respect to practical ingenuity and "thinking outside the box" creativity, and who is also an adept communicator, a bearer of a strong ethical conscience, and an influential public leader (National Academy of Engineering 2004).

Echoes of this perspective can be found in the words of two informatics engineers and designers of a course in critical thinking:

> Critical thinking skills are essential for good and apt decision making and for the understanding of problematic issues, this being especially important for engineering professionals who are expected to make important decisions, solve technical problems, face ethical balances, employ best practices, and report and document their findings and products, as well as act in a consultant capacity. (Pereira and Krippahl 2007)

Good critical thinking skills also make a key contribution to developing "the ability to identify, formulate, and solve engineering problems," a general standard of the US Accreditation Board of Engineering and Technology (ABET) reflected in its *Engineering Criteria 2000* (ABET 1997). The educational leader Carol Christ, who has often challenged the existence of a sharp divide between liberal education and engineering education, endorses chemist and Nobel Prize winner Thomas Cech's idea that it is through the study of different modes of inquiry outside the sciences, particularly the humanities and the arts, that "one learns to distill the critical elements from the irrelevant, synthesize seemingly discordant observations, and develop a strong argument" (Christ 2008, p. 24)—in other words, one learns how to be a critical reasoner.

Among these different modes of inquiry, philosophy has seemed to offer the most promise when it comes to considering how future engineers might acquire the cognitive dispositions of critical thinking (cf. Goldberg 2008). Given how deeply the pursuit of knowledge of the foundations of cogent reasoning runs within philosophy, as well as the fact that critical thinking is a staple of the philosophy curriculum within the US, it is not surprising that engineering should here turn toward philosophy. I want to suggest this turn should be made only with a fair amount of caution, as philosophy-based approaches to critical thinking tend to be dismissive of the use of heuristics, which is arguably a key, distinctive element of engineering reasoning. In fact, philosophy can learn from engineering about the value of heuristical reasoning as a form of critical thinking.

By making this suggestion, my intent is also to underscore how dialogues that have emerged in recent years among philosophers and engineers can benefit those in both groups. Certainly philosophers can, by offering conceptual tools, insights, and modes of inquiry, make incisively valuable contributions toward the development of the philosophy of engineering and to improved practices within reflective engineering and engineering education. But philosophy too stands to benefit from closer conversational contact with engineering (Michelfelder 2008, 2009). Such contact can bring helpful challenges not only with regard to some of the former's basic assumptions but also with regard to its common classroom practices.

2.2 Heuristical Reasoning and Critical Thinking

In the course of tracing the complexities of the relationship between engineering and the liberal arts in the context of the academy, Catherine Koshland finds that engineering is a "practice field" in two separate senses: on the one hand it is a practice field much like the studio arts and creative writing; on the other hand, it is a practice field where "research is inspired by use" (2010, p. 54). The commonality here lies in practice. Engineering design decisions are ones that are always situated, contextualized, made in "real time" and within a framework where design and use are interconnected. They would not be made, as Billy Koen (2003) has pointed out, were it not for the purpose of bringing about change in the world; and because the situations within which such decisions are made are often complex, unstable, ill-defined, and highly variable, engineering decision making needs to be grounded in reasoning suitable to such situations, namely, heuristics. In his well-known definition, the "engineering method is the use of heuristics to cause the best change in a poorly understood situation within the available resources" (Koen 2003, p. 28).

Is heuristical reasoning a form of critical thinking? From one perspective, it would seem the answer surely has to be yes. It is an approach to problem-solving that depends on reflectively thinking through a novel situation in the light of knowledge that has been gained from the course of experience in order to, in the words of Cech quoted by Christ above, "develop a strong argument" for what to do next (Christ 2008, p. 24). Just as critical thinking is not grounded in formal rules of logic, so heuristics are informal strategies of reasoning. Such informality makes the conclusions reached by critical thinking and heuristical reasoning vulnerable, as they are always possibly rather than necessarily true. As any student who has taken a course in critical thinking knows, the standard for evaluation of a typical argument analyzed in such a course is strength, not validity. The same holds for engineering reasoning as Koen describes it: A heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible (2003, p. 28).

The rule "at some point in the project, freeze the design" is a heuristic (Koen 2003, p. 35). So are the rules "plant narcissus bulbs among your tulips to prevent deer from having dinner at your expense" or "if your temperature rises to 102 °F (39 °C), go see a doctor." The latter rules are rules of everyday life; the second of them could be said to be a rule of common sense. In describing engineering reasoning as common sense, Joe Pitt has sought to call attention to how problem- solving in engineering and problem-solving in philosophy have the same form:

> Thinking about what we want to achieve, we choose the option that seems to have the best chance of getting us to our objective. If we fail, as we often do, we go back and look at what we started with and try to figure out what went wrong. We re-examine what we thought we knew…. (Pitt 2013)

From another perspective though, the relationship between heuristical reasoning and critical thinking is more distant. This can be seen when we look beyond the value of heuristics just described—that of providing a plausible argument which helps in choosing one direction to take over another—to another reason why heuristics are valuable in engineering: They are resource-preserving, particularly with respect to time (Koen 2003, p. 29). Rather than pouring over all possible options for solving a particular problem, one takes the option that affords the best chance of success, in the light of knowledge one has at that moment. In some cases, the nature of the decision to be made brings with it a special pressure to save time. Should nations heavily invest in geo-engineering "band-aids" such as spraying sulfate particles into the stratosphere in order to prevent global temperatures from continuing to rise while other, less temporary solutions to climate change are investigated? The consequences of aerosol spraying are unknown; such spraying could lead to unintended, negative effects on the climate. But the consequences of not investing in aerosol spraying research and development could be even more dire. Before the relevant data could be collected, a decision demands to be made.

Given that critical thinking attends to the evaluation of informal arguments in everyday life contexts, it would seem that here we would easily be able to find an emphasis on contexts where good reasoning, reasoning of the sort needed to drive timely decision making, is of the essence. This though turns out not to be the case. The value of saving time in the activity of reasoning is simply not an important value for informal logic. This could have resulted from the standards of formal logic "seeping" into the philosophical discourse of the logic of everyday decision making: For formal logic, where precision of proof is key, thoroughness of thought is both necessary and time-consuming. Wherever the reasons may be, despite the similarities described above between heuristical reasoning and critical thinking, critical thinking textbooks tend for the most part to ignore heuristical reasoning by name (cf. Rainbolt and Dwyer 2012; Vaughn 2010). In one excellent critical thinking textbook where heuristical reasoning is explicitly addressed (Sinnott-Armstrong and Fogelin 2010), both the context—a discussion of fallacies of probabilistic reasoning such as the "Linda problem" made famous by Tversky and Kahneman in a paper from 1974—as well as the substance of what is said send the message that heuristical reasoning is to be exercised with considerable caution. The passage is worth quoting at length:

> In daily life, we often have to make decisions quickly without full information. To deal with this overload of decisions, we commonly employ what cognitive psychologists call heuristics. Technically, a heuristic is a general strategy for solving a problem or coming to a decision…. Recent research in cognitive psychology has shown, first, that human beings rely

> very heavily on heuristics and, second, that we often have too much confidence in them. The result is that our probability judgments often go very wrong, and sometimes our thinking gets utterly mixed up. (Sinnott-Armstrong and Fogelin 2010, p. 279)

The implication is that our everyday ways of heuristical reasoning, rooted in our psychological make-up, are untrustworthy ways of thinking. Such an assessment of the value of heuristics also leads critical thinking to frame specific heuristics as first and foremost fallacies of critical reasoning, and only secondarily as good approaches to problem-solving and decision-making. The *argumentum ad populum* (*AaP*), more commonly known as the fallacy of popular opinion, offers a good case in point.

2.3 The Heuristical Benefits of Critical Thinking Fallacies

As its name suggests, the *argumentum ad populum* makes the claim that if a number of people believe x is true, x is indeed true. In critical thinking textbooks, a two-pronged approach is typically taken in discussing the *AaP*. First and foremost, it is taken a form of fallacious reasoning. Secondarily, it is taken as a form of reasoning that may, *under certain circumstances,* lead to a truthful conclusion. Succinctly put, the *AaP* is seen as a pattern of poor reasoning to which there can be some exceptions.

To illustrate the *AaP* for example, Rainbolt and Dwyer (2012, p. 72) cite an article reporting on the results of a survey ("13,000 Kids Can't Be Wrong," Whelen 2004) showing that nearly all pre-college students questioned by the researchers thought having libraries in their schools improved their learning. From here the authors observe:

> The fact that 99.4 % of students believe that something is true doesn't indicate that it's true. Elementary and high-school students have little information about the benefits and costs of school libraries. Thirteen thousand kids could be wrong. (Rainbolt and Dwyer 2012, p. 73)

Vaughn (2010, p. 175) notes that only when the number of people who believe x is true are in fact "experts" with regard to x does it make sense to see the *AaP* as an instance of non-fallacious reasoning. Sinnott-Armstrong and Fogelin (2010, p. 265) take a related approach to dividing fallacious *AaPs* from non-fallacious ones, noting that popular opinion can often be trusted when the opinion is of something about which many people can be assumed to be knowledgeable, such as whether a particular book is entertaining. From these two perspectives, it strikes me that the conclusion reached in the example given just above is doubtful, as those surveyed would seem to be experts by virtue of their position as "end users." The point here though is not to call this conclusion into dispute. It is rather to call attention to how the *AaP* and by extension many other informal fallacies-as the *AaP* can stand as a proxy for the fallacy of hasty generalization and a number of others—are generally framed and presented: as primarily forms of bad reasoning which have exceptions under particular circumstances.

Any reader who has reached this point might reasonably wonder just what the issue here is. Without question, instantiations of the AaP *represent* in many cases fallacious reasoning. The fact that many people once believed in a flat earth did not make "the earth is flat" a true proposition. Thinking along these lines, the frame just described seems unproblematic.

But what if common, informal fallacies such as the *AaP* are interpreted as heuristics—in other words, if they are taken as rules-of-thumb that help individuals in making problem- solving decisions in a timely manner? In an interesting and provocative paper, "Logical Fallacies as Informational Shortcuts", Luciano Floridi (2009) explores the heuristical benefits of fallacies of reasoning, giving most of his attention to two fallacies which, while also standard points of consideration in critical thinking courses, fall within the realm of formal deductive reasoning: denying the antecedent and affirming the consequent, or "backwards reasoning." The gist of Floridi's argument is that while according to the principles of formal logic these patterns are generally treated as deficiencies of reasoning, in the course of everyday life their use can often be both effective (in terms of leading to a truthful conclusion) and efficient (in terms of cutting down on the time it takes to solve a problem). In identifying these patterns to be basically Bayesian shortcuts that allow someone to "cut to the chase" and arrive at a conclusion by sorting through less information than someone who is reasoning more "properly" by current standards of critical thinking, he calls for them to be taken out of the "dustbin" to which Aristotle long ago consigned them and rehabilitated as "informational shortcuts that can be epistemically fruitful if carefully managed" (Floridi 2009, pp. 396–397). "Informational shortcuts" are, of course, just another way of speaking about heuristics.

Without going into any great detail, Floridi also notes that some informal fallacies, including the slippery slope argument, may also on occasion be viewed as rational forms of reasoning (2009, pp. 401–402). Left unexplored in his paper are their benefits as heuristics in situations where problems arise and demand a timely solution. In such situations the *AaP* would appear to be an informal fallacy with strong heuristical value. When it comes to making decisions about a variety of consumer-related questions—from purchasing anything from a lightbulb to an automobile to choosing what restaurant would be best for dinner—individuals frequently rely upon the *AaP* for the sake of decreased time and increased accuracy in their decision-making. Another common use of the *AaP* is as a "fall-back" heuristic when the "backwards reasoning" heuristic yields poor results. Imagine I pull into my driveway, but cannot get my garage door to raise when I press the button on the automatic opener. Because of severe storms in the area, my electricity had gone out the day before. I conclude the garage door is not opening because the power has once again gone out, but when I open my front door I see the lights are on. Rather than re-applying the "backwards reasoning" heuristic using another premise, I search on the web for "most common reason for garage door not working"; if I am able to find a reason that stands out above the rest, based on what others say who have found themselves in similar situations, I might then know what to do next.

One might say that drawing a conclusion using the *AaP* in a world where practical knowledge is increasingly formed as a result of online "crowd-sourcing", makes reliance on this form of reasoning a less risky enterprise. In an interview for the *IEEE Spectrum,* Trevor Pinch raises doubts about the trustworthiness of online consumer reviews, given how easy it is for reviewers to "game the system" in order to increase sales and ratings (May 2013, p. 26). Pinch's concerns are understandable; such risks do exist. But it is more reasonable to think these risks are outweighed by positives enabled by the technology of the Internet, including the checks and balances offered by individuals posting honest and informed opinions and by the availability of multiple websites offering reviews of the same item.

In short: critical thinking fallacies have heuristical benefits that often go unrecognized in critical thinking textbooks. If engineering students are learning critical thinking skills in courses where such textbooks are used, it could lead to them putting less rather than more trust in their own capabilities of thinking, an outcome which is exactly the opposite of what critical thinking hopes to achieve. Learning critical thinking skills should be confidence-inspiring in this regard, not confidence-reducing. While a confidence- reducing outcome is particularly undesirable for engineering students who are otherwise taught the value of heuristics in design courses, it is also undesirable for students of philosophy and other disciplines due to the potential for erosion of trust in one's own cognitive powers. Some suggestions for how this outcome might be avoided follow.

2.4 Critical Thinking Revisited

Heuristics can fail to give reliable results and when this happens the consequences can be devastating. Consider the Deepwater Horizon accident on 20 April 2013 (see Deepwater Horizon 2013), which initially resulted in a loss of eleven lives from the blowout of the BP managed oil well on the rig; hydrocarbon emissions from the well for nearly 3 months afterward contaminated waters in the Gulf of Mexico, estuaries, and beaches along the Gulf Coast, resulting in extensive destruction to natural habitats and marine populations (BP 2010, p. 9; Robison 2013). In its internal investigation of the Deepwater Horizon accident, BP identified a complex sequence of decision-points and events in the hours immediately leading up to the blowout (BP 2010). One of the events was a negative pressure test, designed to determine well integrity. One of the decision-points came when the results of the negative pressure test did not square with the fact that the drill pipe pressure had risen to a point of 1400 PSI. The latter was attributed to a phenomenon called the "bladder effect." Once that heuristc was accepted, the negative pressure test was treated as successful (BP 2010, pp. 87–89). Shortly thereafter, the blowout took place.

When heuristical reasoning fails to give reliable results, doubts about the fallibility of one's own reasoning ability naturally follow. Such doubts are fueled by what amounts to a small "cottage industry" of recent publications in cognitive psychology, behavioral economics, and other disciplines. Aimed at a general, well-educated audience, such research is designed to show how our powers of observation are not as veridical as we think they are and that we frequently make misjudgments both about external states of affairs and our own inner states (e.g. Kahneman 2011; Thaler and Sunstein 2009).

Nonetheless, even though heuristics are by definition potentially fallible, they are often reliable as well. Heuristical reasoning is the kind of reasoning that engineers and philosophers alike most often draw upon when confronting real-world problems under time constraints, as well as the arguments that support decision making about these problems that lead to the creation of new artifacts, systems, and public policies. To put this point more forcefully, *The Engineer of 2020* report notes that while engineers have always been concerned with problem identification and problem solving, the problems that they are likely to confront will be different from those of the past in terms of "magnitude, scope, and impact" and that "by 2020 the need for practical solutions will be at or near critical stage" (NAE 2004, p. 55). This highlights the need for learning how to think rationally under unpredictable conditions that extend beyond being time-sensitive to being urgent, not only for engineering students but also for philosophy students who want their work to be impactful in terms of creating change in the world. A small but essential part of that need could be met if the dominant approach to teaching critical thinking were revised.

What more specifically might be done to bring about this change? One way for engineers to help philosophers see the positive value of heuristics in critical thinking courses would be through team-teaching; such an approach might naturally lead to an emphasis on evaluating arguments in both personal and professional settings where timely decision-making is key. It could also have a collateral effect of assisting engineering students to see that engineering problems can also be social problems, and helping philosophy students to see that many social problems also have engineering components. Some critical thinking textbooks include arguments for practice evaluation purposes from the fields of law, science, and religion (Sinnott-Armstrong and Fogelin 2010); extending this coverage to look at engineering design decisions would also be helpful. But my primary suggestion would be to change the dominant frame described earlier for talking about logical fallacies, in which they are first seen as models of deficient reasoning and secondarily as instances of good thinking. One way this frame might be changed is by easing the word 'fallacy' in critical thinking textbooks into retirement and using it sparingly in the future, giving explicit preference to the word "heuristic".

Such practical changes also relate directly and indirectly to continuing to take the developing conversations between engineering and philosophy into the classroom. It is arguably in this setting that these conversations have the best chance for being genuine two-way streets. Within the world of philosophy, the "philosopher of 2020" has not been discussed or described. But just as philosophy can contribute to the formation of the engineer of 2020 through the teaching of critical thinking skills, were there to be a philosopher of 2020, by challenging the dominant approach to teaching about critical thinking fallacies, engineering could contribute to their formation as well.

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Chapter 3
Ontology of Technical Artifacts: A Proposal

Hans POSER

> *If there are no artifacts, then there are no philosophical problems about artifacts.*
> *—Peter van Inwagen (1990, p. 128)*
> *We need not conceive of … artifactual kinds as existing and having their natures entirely independently of all beliefs in order to treat them ontologically seriously.*
> —Amie L. Thomasson (2003)

Abstract This general exploration of discussions about the ontology of technical artifacts begins with a brief summary of views of Aristotle and Kant that have implications for contemporary proposals for an engineering ontology. It then argues for an extension of the dual natures analysis developed by Peter Kroes and others that would take into account causality, creativity, intentionality, and finality. This new proposal draws on the work of Karl Popper and especially Nicolai Hartmann. I emphasize, however, that this is only a proposal that remains to be elaborated.

3.1 Introduction

Ontology inquires about the existence of whatever object there are, for their fundamental properties and relations, their basic categories related to the fundamental structure of being. Special ontology limits this inquiry to some special region of objects. Artifacts doubtlessly are among the entities of the real world; and artifacts of the fine arts have been the object of ontological inquiry (Ingarden 1931; see Livingston 2012). However, the ontology of technical artifacts is a new branch, with two different nodes.

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The first node comprises the information science ontology (e.g., Borgo and Vieu 2009), which is broadly established; it aims to develop a computer language for special sciences, such as a uniform formal language for the different disciplines of medicine. For this purpose, Barry Smith has built up an extended National Center for Ontological Research at Buffalo (Smith and Ceusters 2010). In the field of economics we can observe a similar movement (Hepp et al. 2008). Even though the guiding idea behind this branch is usefulness, it is somewhat misleading to call all this "ontology," when the traditional philosophical meaning is considered, which seeks to analyze the existence of entities and their basic categories.

The second node is concerned with technical artifacts that depend on the engineering sciences (let us call it an engineering ontology or EO). The most well developed contributions to this approach have emerged from the "dual natures of technical artifacts" research program that analyzes engineered artifacts as both physical and social objects. See the EO work in Meijers (2000), Lawson (2007, 2008), Pohjola (2007), and Kroes (2012). This is a fruitful approach, since on one side, artifacts follow causal laws and, on another, are intentionally created for certain purposes. Yet it requires important extensions: the central problem involves bridging the two sides. Understanding technical artifacts as constitutions (Baker 2004, p. 99) founded on successful intentions (Thomasson 2007a, 2009) point the way toward a solution. However, the extension requires not only the inclusion of classical causality and mental intentionality, but also creativity and finality as a teleological "downward causation." This is one of the points that demands a many-level EO, as will be proposed here by extending the approach of Nicolai Hartmann (1931, 1940, 1942/1953).

3.2 Background

Ontology goes back to Aristotle (*Metaphysics* 1003a20), even though the term is much younger. Any ontology is part of metaphysics, since it deals with questions that belong neither to formal nor to the empirical and technological sciences. Yet most contributions are realistic in an anti-metaphysical sense.

In the present instance, metaphysics is understood as lacking strict empirical or formal foundations, but positing a hypothetical, orienting structure open to critical revision (Poser 1990). Such a view has been accepted in speaking of possibility, causality, intentions, and functions, since none are observable, but depend on interpretation.

Back to Aristotle: For Aristotle existence was constituted at multiple levels in a hierarchy beginning with pure matter (*hyle*), followed by material objects, living beings, psyche, and mind, depending on distinctions between matter and form, which come together in existing entities and are connected by the four *causae*, namely *materialis*, *formalis*, *efficiens,* and *finalis*. However, pure matter does not exist as such, and form as separated from matter by abstraction are elements of the mind. This approach is fruitful because it shows how rich an ontology can be. Yet technical artifacts find no special place in Aristotelian ontology because their efficacy or finality is not their own property, but stems from the human being who makes it (his example is a builder constructing a house, indicating that cause and purpose are not part of the house (*Metaphysics* 1014a1–10). Nevertheless, we can learn from Aristotle that finality is a fruitful metaphysical concept, even though he took it as a descriptive term.

Ontology asks questions about existence or being. Some passages from Immanuel Kant's *Critique of Pure Reason* that formulate its fundamental problem are as follows:

> "Being" is obviously not a real predicate; that is, it is not a concept of something which could be added to the concept of a thing. It is merely the positing of a thing, or of certain determinations, as existing in themselves. (A 598/B 626; trans. Kemp Smith)

> By whatever and by however many predicates we may think a thing—even if we completely determine it—we do not make the least addition to the thing when we further declare that this thing is. Otherwise, it would not be exactly the same thing that exists, but something more than we had thought in the concept; and we could not, therefore, say that the exact object of my concept exists. (A 600/B 628; trans. Kemp Smith)

> A hundred real thalers do not contain the least coin more than a hundred possible thalers. (A 599/B 627; trans. Kemp Smith)

In fact, Kant used his category of existence only for real bodies, neither for possibilities nor for God. As a consequence, ontology depends on epistemological conditions. Even if the transcendental approach is rejected, because of Kant the practice of ontology has changed. It has become "realistic"—while nevertheless allowing us to speak of other elements as well, such as natural numbers, intentions, values, or of ideas. What is taken as being or existence depends on limiting conditions. Formally, this corresponds to Willard V.O. Quine's well-known dictum: "To be is to be the value of a [bound] variable" (1964, p. 15)—but presupposing always a special universe of discourse, relying on a preliminary decision "on what there is." Therefore, ontology has to deal with the question: Which kinds of objects are accepted as really existing? If our universe of discourse consists of heraldic animals, unicorns doubtless exist. Yet the more important question is, how to deal with different universes—possibilities, ideas, bodies, or artifacts. They cannot be mixed up as one universe of discourse. Ontology has to impose an ordering, after the manner of Aristotle. This will precisely be the primary problem for EO.

In this sense, Amie L. Thomasson writes (by the way, against the radical allegedly realistic position, which says that artifacts do not really exist): "So we can say that artifacts are not just causally but existentially dependent on minds, in the sense that it is metaphysically necessary for something to be an artifact that there be intentional human activities" (2009, p. 194). The dual nature of artifacts also necessitates introduction of the concepts of creativity and finality, which reveals that the intentions of their creators are aim-oriented, and that users expect the artifact to function as a means of attaining an end.

Why is such an extension of what there is acceptable? Because seen from life experience, intentionality and finality are the basis of human action. Human beings imagine new artifacts, think about possible aims and means, evaluate them, and select those to pursue: intentionality is a basic human capacity that is essential for the development and use of artifacts, even if we cannot observe an intention—but it is the outcome of an interpretation. Similarly with creativity: it indicates something new, freely developed by the human mind. It is impossible to give a definition of creativity; if we could do so, it would not be creativity, because "defining" means reducing to other already known concepts. This is no intellectual catastrophe, since concerning modalities, we are not better off—they have no empirical foundation and they cannot be defined. This is it why Kant takes modalities as transcendental categories, whereas Alfred North Whitehead introduces creativity as one of his fundamental ontological categories. Yet all of us know from our own mental experience what creativity means and what it is. Since each new technology goes back to a creative idea, we have to include creativity as well as its state as an idea, as essential element of an artifact and, consequently, of EO. Research on brain activities may show where intentionality and creativity go on in the grey cells, in synapses, etc. But even if we could extract the electric impulses of the nervous net in question, this is neither an explanation nor a reduction to causality, because the semantic interpretation of brain processes presupposes what has to be explained, namely, intentionality and creativity.

3.3 Problems and Reactions

Without a doubt, technical artifacts follow causality; this is the first essential property of artifacts, which is never criticized. Yet the inclusion of creativity, intentionality, and finality as well as their coming together with causality requires that they are connected to quite different regions of existence. Therefore, extensions of the dual nature of artifacts are needed in order to develop a more adequate EO:

(i) Causality as well as finality concern processes. Since artifacts are seen as objects, connected with processes, EO must include objects and processes.
(ii) Causality of natural laws warrants that the process of an artifact leads to the intended end. Yet even malfunctions happen causally. Finality concerning an artifact depends on two different intentional processes: on one side, the process of creation, development, and realization in the perspective of factual or anticipated societal needs; on the other (with regard to the user), the process of application. Both causality and finality belong to different universes of discourse. Since they come together in any artifact, a kind of connection has to be established by EO.
(iii) Technical artifacts are "creations of the mind" (Thomasson 2007a, p. 52); this requires that creativity be included in EO.
(iv) The finality of developing and using an artifact rests on aims, which go back to values: therefore artifacts include a normative element, which has to be included in EO.

(v) Technical objects and processes range from mechanical and bio-artifacts via hybrids to non-material artifacts such as computer programs, which differ from their material bearers. Therefore, EO must comprise a broad sphere encompassing entities from the material to the immaterial.

These five EO issues are only a beginning. The second point together with the third and the last one suggest further difficulties, since the objects of different ontological layers follow different laws or rules: a steam engine as a material object obeys causal and thermodynamic laws in its dynamic process; a bio-artifact such as the sheep Dolly follows biological laws of growth; a CAD program follows imposed syntactical rules. The layer of actions involved in the process of developing and using an artifact depends on a reflection of possibilities under value constraints. Yet, all these kinds of laws and rules are constitutive elements of an artifact; hence, they have to be integrated in EO.

Technical objects and processes are never isolated, but part of some system, which might be relatively closed, such as a machine for the production of screws (embedded in a further system of traffic, energy, raw materials, trained workers, etc.) or quite open, as a computer (which is produced for open possibilities, so it has by no means only a single essential function). This implies that EO needs a mereology, asking for the part/whole-relationship, which operates within system hierarchies. The problems of a mereology of technical artifacts cannot be discussed here in detail (see Simons 1987). Yet two observations can be useful. Naturally, it is much too narrow, if only screw-divers, corkscrews, and paperclips are taken into account as objects, as is done in the case of many papers on philosophy of technology. Even screw-drivers presuppose screws and the production of screws; paperclips need paper and paper production, and so on. Both cases further presuppose a society that uses screws instead of glue or rivets, and paper instead of computer memory sticks.

Now it is remarkable that Pieter Vermaas and Pawel Garbacz (2009) make it clear that when artifact ontology is concerned, one should not look for parts as physical objects, but for functions and sub-functions. This fits together not only with the way of developing new technologies, but it also indicates that one of the central terms of EO, namely function, denotes a process, explicitly a means-end process; this holds good for meta- and sub-systems as well. Yet this is connected with several difficulties, since a function includes highly different objects: the function to indicate time can be fulfilled by quartz watches, sun dials, or water clocks, contrary to the traditional understanding of ontological kinds. Furthermore, several artifacts have many functions, as with the computer. Finally, function needs an explanation of its teleology: how is it possible to manage causality for our purposes? All this needs to find a place in EO.

There have been several proposals about how to bridge the causality-teleology gap between the material, causal side, and the intentional aim-oriented side, which is the core issue for the dual natures research program. These proposals usually begin with the concept of function. The concept of technical function is then used to install a connection, taking this as a union of a causal function and a societal one.

Such is the dual natures solution, elaborated, among others, by Peter Kroes. Technical artifacts depend on technical functions installed by "human intentions and physical features" (Kroes 2012, p. 59). This is helpful but not sufficient: it has marked the gap but does not close it. The structures of both kinds of functions differ. To speak of a causal function consists of an interpretation of a causal relationship as a means-end-relationship (already Dipert 1993, p. 77), yet this is inadequate for causal processes as such.

A second proposal has been that of the Constitution View, developed by Lynne Rudder Baker. According to Baker,

> Constitution is a relation between things of different primary kinds. Constitution brings into existence new objects of higher-level primary kinds than what was there before. (2004, p. 100)

Or somewhat later: Constitution is "a single comprehensive metaphysical relation that unites items at different levels of reality into the objects that we experience in everyday life" (Baker 2007, p. 32). Baker takes a constitution as a "unity-without-identity" and a "contingent and time-bound relation" (2008b, p. 1). Moreover,

> artifacts and artworks are paradigmatically ID [intention-dependent] objects, and they too bear constitution relations …. The circumstances required for the existence of ID objects (like voting machines or statues) have presuppositions of intentionality. (Baker 2008a, p. 13)

This is fruitful, since a differing new use of an artifact can be included, when the intention has changed. Even malfunctioning is integrated (Baker 2009), instead of being forced to say (if correct functioning is the essence of an artifact) that in cases of malfunction, the artifact in question has lost its existence (Grandy 2007).

All this shows that Baker's constitution depends in its ontology on primary kinds, which generate higher-level primary kinds. This is a process; and to explain that it really produces something new, one has to introduce theories of complexity, e.g., of dissipative or autopoietic structures (which means including not only contingency, as she does, but blind chance as well) or intentionality as a directional force (which leaves open the question how intentionality can, in fact, bring about a kind of constitution obeying causal laws in order to reach the intended efficiency of the artifact). To say that primary kinds can be "determined by function" (Baker 2009) is merely a postulate. So the bridge needed for closing the gap is missing.

A third approach can be seen in Thomasson's idea. Following a "purely descriptive approach," she takes artifacts as "the intended products of intentional human activities" (Thomasson 2009, pp. 193 and 195). Concerning the existence conditions, she introduces a purely formal criterion: "for any term '*K*', things of kind *K* exist just in case the application conditions criterially associated with proper use of the term are met" (2009, p. 197). This combines facts about meaning and intention with an empirical inquiry in a "hybrid theory of reference," as she calls it. She argues that "for any essentially artifactual kind *K* something is a *K* only if it is the product of a largely successful intention to make something of kind *K*" (2009, p. 206). This allows us to say that technical artifacts really do exist, even if they are mind-dependent and intentional. Further, it uses a criterion that connects the conceptual and intentional side with the practical side, both of which are taken as realities. This broadens the whole approach. However, it presupposes that humans can create something new, which causally fulfills the intended function, whereas the creative process of successful making is not integrated in it.

Moreover, artifacts as objects in connection with processes at the same time mirror our knowledge in a broad sense. This knowledge does not (or not yet) presuppose why a process in question is working following the Hempel-Oppenheim scheme. It is enough to know that the so-called causal function can be reproduced. In differing from classical metaphysical ontologies, all this shows that EO is no ontology of eternal objects or things in themselves, but a kind of ordering structure, going back to our experience and our theoretical and practical knowledge. Therefore, artifacts should not be seen bottom up from matter to society, but the other way round: from humans down to manipulated objects and processes.

As Thomasson (2009, p. 209) writes, the elements just mentioned can be illuminated by an example from archeology: archeologists are able to reconstruct all these elements from their findings. Let us have a look at the Antikythera mechanism as a piece of evidence. It was recovered by sponge divers a century ago near the island Antikythera and reconstructed for the first time by Derek de Solla Price (1974). A new analyses has recently been carried out by Alexander Jones (2012). The findings are as follows: the artifact is made of bronze; it is a gear wheel construction with inscriptions. The functions of this article of trade can be listed as an analog computer for astronomical positions, a sun calendar, an Egyptian calendar, a lunar mechanism, an instrument for the timing of the Olympic Games, an instrument for finding the position of the planets, etc.—altogether constructed on theories of astronomy and mathematics. The consequences for EO are evident: This artifact shows an extremely extended materialized know-how, considering the production of the bronze mechanism. It bears non-material information, documented by the inscriptions. Considering its functions, it has materialized commercial as well as scientific value, showing an extended materialized theoretical knowledge, which altogether is a document of ingenious materialized creativity. To sum up as a thesis:

> Technical artifacts express materialized intention, materialized creativity, materialized knowledge, materialized know-how, materialization of values, and thus, of culture and history—expressed in the function and its realization as a process and as an object. Therefore, EO must see artifacts in a much broader perspective than the three sketched above, dominated by the dual natures problems only.

3.4 Toward a New Proposal

To begin, the difficulties may be repeated: we have to include creativity, finality, values, modality, and several layers of kinds of reality. In the background there is Aristotle's ontology that was realistic in its four layers, connected by the categories of causality and finality. However, ontology must not be seen as *prima philosophia*; it must include artifacts.

As a first step, it will be helpful to pick up Karl Popper's three worlds theory: world 1 of physical objects and states, world 2 of the mental state or state of consciousness of individuals, and world 3 of partly autonomous contents of thoughts, created by humans, but independent from them (Popper 1973). These worlds are ontologically distinct. Manjari Chakrabarty (2012) proposes to understand world 3 not just as the region of knowledge, theories, values, and ideas, but as including all human creations, namely "social institutions and artifacts." Yet accepting that "artifacts are conceptually dependent on the human mind" does not imply this; moreover, Popper—who only in passing and occasionally deals with artifacts—explicitly states that "inmates" of world 3 are among other theoretical elements "the *contents* of journals, books, and libraries" (Popper 1973, p. 107; italics added), not the physical books themselves. What Popper argues for is a dual ontological state of artifacts: for books as material objects belong to world 1, and because of their form and content, to world 3. The more interesting point is a different one: in Popper, houses, tools, and works of art are products of human activities. These productive acts actualize objective (i.e., world 3) structures in world 1 and just this is what requires explanation.

Popper's approach was initiated by Donald T. Campbell, who introduced a kind of biological downward causation (Campbell 1974, picked up by Popper (1978). This approach has been strongly criticized, but is the kind of teleology needed to connect world 3 via world 2 with world 1: we have to understand downward causation as finality, even if—as Campbell admits—the term "causation" might be misleading.

Nevertheless, Popper was not trying to develop an ontology. It will thus be useful to turn to an ontological approach that may to be extended to artifacts. Such an approach has been broadly developed by Nicolai Hartmann, although he does not explicitly deal with artifacts. He aims to integrate "the being of objects and humans, the reality of the material and the mental world" (Hartmann 1931, pp. 7–8). We need this extended concept of reality, since technology always bridges both aspects, today even more than in the past. Consider, for example, computer simulation and automated control and the non-material artifacts known as programs. At the same time, Hartmann understood his New Ontology in a way that corresponds to Popper's "common sense realism" (Popper 1973, p. 37):

> One can recognize only what "is", and that means: what exists also independent of recognition, so what is "in itself". The whole "subject – object" relationship is … moved to another dimension. It is a transcendent ratio, namely transcending awareness: a relation connecting the consciousness with something independent of it. (Hartmann 1931, p. 9)

The realistic metaphysical presupposition is that there are objects independent of cognition. This comes together with Hartmann's basic principle: "The categories of being are not a priori principles." More: "They are rather gleaned step by step from an observation of existing realities" (Hartmann 1953, p. 14). These realities include objects and processes, possibilities, intentions, sensations, and ideas; and "mind

[*Geist* – trans. as spirit] is, and remains, bound to the body" (Hartmann 1953, p. 34). This is a modern approach, which causes no difficulties for including intentions as a precondition for the development and use of artifacts.

All this is connected in strata of being, in which the categories participate. As in Aristotle, there are four strata: the inorganic, the organic, the psychological, and the mental (Hartmann 1940, pp. 197–200; 1953, p. 4). However, these are by no means layers of things: "the hierarchy of strata such as matter, life, soul, and mind" differs completely from "the hierarchy of actual structures … represented by inanimate object, plant, animal, man, community" (Hartmann 1953, p. 105f), since the ontological strata are characterized by differing categories. Therefore, Hartmann's ontology is built from the beginning on specific categories coming together in one stratum (see Hartmann 1953, p. 64):

- Corporeal world: "space and time, process and condition, substantiality and causality."
- Animate nature: "organic structure, adaptation and purposiveness, metabolism, self-regulation, self-restoration, the life of the species, the constancy of the species and variation."
- Psychological reality: "act and content, consciousness and unconsciousness, pleasure and displeasure."
- Realm of the mind: "thought, knowledge, will, freedom, evaluation, personality."

Underlying these special categories are highly general ones, common to all strata, but varying from one to another in specific ways. These fundamental categories are "unity and multiplicity, concord and discord, contrast and dimension, discretion and continuity, substratum and relation, element and structure, … form and material, inner and outer determination, … identity and difference, generality and individuality, … the modal categories: possibility, actuality, necessity, and their negative counterparts." (Hartmann 1953, p. 66).

Additionally, the strata are connected. They are clearly separated, but built one on the other. From the material to organic this transformation is a "superinformation" (*Überformungsverhältnis*) that proceeds from the structures of the lower stratum to the higher without loss, so that new structures of the higher stratum are not reducible to lower ones. Similarly, the stratum of consciousness requires matter and body, yet the new stratum transforms those categories not as superinformation but as a "superimposition" (*Überbauungsverhältnis*) (Hartmann 1953, p. 79). Some, but not all categories, of the lower strata (e.g. causality, interaction, status, process, time) apply in a transformed mode in higher strata; e.g., the forms of causality follow in animate nature a different kind of determination than at the inorganic level. Within this transformation, each higher stratum is characterized by novelties, as the above list of categories shows: The psychological reality is non-spatial, and marked by individuality and the interiority of psychological contents. The mental realm—again as a superimposition reshaping—differs from the psychological stratum by independence from individuality as a "super-individuality": there are elements which humans have in common, such as language, moral laws, or religion.

The forms of the mental establish a connection passed from generation to generation. Higher forms of a unity—as humans or societies—arise as novelties only on the basis of the whole underlying strata. What is real or existing finds its place in and across the four strata. Just this basic understanding of the relationship of the strata fits in with contemporary views, even if it is labeled differently, namely as emergence or supervenience. This is unlike a reductionist ontology that accepts nothing but the existence of material things.

The novelties comprising irreducible categories of a stratum have a further and highly important significance: they indicate that the lower stratum has not fixed and determined everything, which means that there are possibilities left open, and these constitute the new stratum. To give an example: The stratum of matter is characterized by the category of causality. This means that each process from its beginning to its end follows causal laws; but these laws, by no means, fix the beginning. Therefore, the higher stratum of life can introduce life processes, which do not contradict causality, but can, so to say, make use of them. The same holds for the new category of intentionality in the psychological stratum: It has the possibility of installing conditions that allow using causality in the lower stratum in a means-end-relationship. Or on the mental stratum: Moral laws or cultural needs can "determine" the intentions of the lower physiological stratum.

All this holds good for creativity as well: As human beings we are free in bringing about new ideas, since the mental stratum is free in an emphatic sense. Free will is, as Hartmann (1953, p. 124) explains, only a special case of the autonomy of the higher stratum in relation to the lower one. This will be the central element of a solution of the EO problems.

Finally, Hartmann introduces laws expressing relationships between different strata, although for our purpose the previous sketchy remarks may be sufficient. Still, there are some further helpful hints concerning our guiding problem of finality. According to Hartmann, with thinking of human beings, society, and historical processes "causal determination is combined with the final determination [*causa finalis*], which always emanates from the human being, for any political plan, for any technological invention" (Hartmann 1956, p. 133). Here he does mention technology. Behind each artifact there is "purposiveness, [which] presupposes an intelligence positing purposes and operating in accordance with them" (Hartmann 1953, p. 55). This corresponds to the intentionality that takes center-stage for Riso Hilpinen (2011) and Thomasson. Hartmann's view is in accordance with these approaches, and includes them in a way that meets Popper's intentions as well:

> The teleological nexus is not simply the reversal of the causal nexus. Its structure is considerably more complicated. Three stages can be distinguished: the conception of a purpose, the choice of means, and the realization of the purpose through the means. The first two stages take place in the consciousness; the third is an actual process taking place in the outer world. The middle stage is actually the characteristic one, for the choice of means proceeds from the conceived purpose backwards to the first act with which realization commences. This retro-determination of the means has the result that the teleological process is determined by its end (the purpose). (Hartmann 1953, p. 71)

This describes clearly a pathway from intention via evaluation to the causal process. It corresponds, too, with our remark on the Hempel-Oppenheim scheme and the practical syllogism. But what remains is the question: How is this way possible?

A human mind-led intervention in nature does not imply that categories of the top stratum change those of the bottom. Lower level structures and laws are not changed or canceled; this would be “beyond man’s power” (Hartmann 1953, p. 120). Just because the world of things is determined in its processes by classical causation, and because this depends on limits that do not exclude interactions, humans can set aims to steer the world for their purposes:

> The three phases through which the teleological nexus develops must here be remembered. Phases one and two, the setting of purposes and the retroactive selection of means, take place in the consciousness, because only consciousness can mentally anticipate the course of time and then move backwards in the opposite direction. The third phase, however, is a real process running parallel to time: the realization of the end by the same series of means that has been traversed in the second phase, only in reverse order. Moreover this process of reality is a simple causal process. For in it, the means ‘effect’ the end. They now form a chain of causes, and they are selected with a view to just this their causal operation. Thus the causal nexus is not only a condition of the teleological process but is also included in its third phase. The fact that the first two phases precede the causal nexus is the basis of the superinformation to which the causal process is subjected by the teleological process. (Hartmann 1953, p. 131f)

This is exactly an explanation of Popper’s and Campbell’s downward causation within an ontological framework. The novelties of each stratum open the way top down. So finality as the essential metaphysical assumption has found its place not only in purposeful action, but also in any development and use of technical artifacts. Moreover, all the other points named above find their place in the extension of Hartmann’s ontology to EO: Each stratum presupposes the existence of the underlying ones. Most important is finality as the transformation top down, a teleological element. Humans belong to all four strata. They can be creative, develop new artifacts based on their knowledge and know-how, and realize them through actions. Their intentions depend on knowledge and cultural values, which belong to the fourth stratum. Even more significantly, humans, societies, and historical processes “cut across” these four strata (Hartmann 1953, p. 48).

All this holds for technical artifacts, including bio-artifacts and immaterial artifacts as well: They are created, produced, and used by humans. Hence, they depend on and express elements of the third and fourth strata, whereas the causal and biodynamic sides belong to the first and the second stratum. This warrants attributing creativity and finality to technical artifacts, because humans impose these via their aim-directed intentions and actions. This model includes what we need: causality and finality for processes; creativity, knowledge, values, intentions, and materialized functions as an expression of culture; and modalities concerning the whole structure.

As a last step, one might consider eliminating some categories involved with artifacts, although this will be difficult. Remember that the ontological approaches of Baker (2000, 2007) and Thomasson (2007b), from their very beginning, include technical artifacts in a much broader and more general ontology—namely by the constitution view and by considering ordinary objects, respectively. Their methodological approaches leave dual nature gaps to be bridged. It was this that necessitated introduction of the category of finality in order to explain intentionality and function. Therefore, a widening was unavoidable. Thinking of material artifacts, one might try to eliminate Hartmann's second stratum completely; yet it entails the presupposition of human intentions, theoretical knowledge, and values. Looking at the third stratum, one might argue that pleasure and pain can be eliminated; but a CD player together with a J.S. Bach CD are produced and used with the intention of giving enjoyment. As for the realm of the mind, one might argue that free will, freedom, and personality as categories make no sense when thinking of artifacts. However, all this is involved in artifacts: without free will, neither creativity nor intentionality would be possible; and patents show that personality is included. So one approach this issue the other way around: since the existence of technical artifacts is completely dependent on humans (even in cases of industrialized production of copies, discussed by Crawford L. Elder 2007), it is no surprise that EO coincides with an ontology rich enough to include the categories expressing the being of humans.

3.5 Conclusion

All this is only a proposal. It remains to be elaborated. It is not yet a solution. The intention had been to show that an extension of Nicolai Hartmann's ontology leads to an approach that is characterized by a much broader frame of layers and of categories and is suitable for EO. The proposal allows speaking of intentionality in a way that includes, on the one side, values and reflection on ends and means and, on the other, connections with causality, coming together in a dual nature of technical functions, corresponding to Thomasson's two-sided criterion of reality for technical artifacts. It includes objects and processes as well as the determining power of rational decisions depending on values, know-how, and knowledge in their historical changes, since Hartmann understands "mind" in the sense of Popper's world 3.

All this is open to critical alterations, because it differs from Kant's transcendental deduction of the categories. Here the categories are gleaned from existing reality. Moreover, since categories might pass over from one stratum to the other, their transformations can be included as well, showing connections among the strata. Finally, the whole approach avoids reductionism, since artifacts depend essentially on the different kinds of reality found in knowledge, intentions, and causality (including biological laws). Thus, the proposal integrates the fruitful analyses developed so far, and opens a new perspective.

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Chapter 4
Toward an Experimental Philosophy of Engineering

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Abstract Many philosophers have criticized technology and engineering. One common criticism is that modern technology and engineering degrade human beings, limit their freedom, and threaten the contemporary democratic order. To address such criticisms, it has been argued that modern technology and engineering must be reconstructed so that they are humanized and democratized. Other philosophers argue that technology and engineering reveal and embody human nature, unfolding opportunities for the development and improvement of humankind. Another approach to the question of technology and engineering is through an experimental philosophy that views both engineering and human nature from the perspective of evolution. Such a perspective helps us toward a new appreciation of the inherently humanizing possibilities in technology and engineering. In this sense, the issue is not about humanizing technology and engineering; rather, it is about responding to questions about what kind of beings we want to become.

4.1 Introduction

Historically, there have been two attitudes toward technology and engineering. One involves a hope to return to the past: it assumes that human beings were at home in the world as it once was, but that human beings left this home and lost their way. The other involves a belief that human beings can create a better home for themselves in the future and that this home needs to be constructed and continuously reconstructed. The latter is more common today and seems more practical. How to construct and reconstruct such a home with technology and engineering remains a major question for humankind.

Many philosophers have criticized technology and engineering (see Mitcham 1994). One common criticism is that modern technology and engineering degrade human beings, limit their freedom, and threaten the contemporary democratic order.

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To address this criticism, it has been argued that modern technology and engineering must be reconstructed so that they are humanized and democratized. In some cases, discussions reference ideas of human nature, about which there are many debates. Other philosophers argue that technology and engineering are artificial, revealing and embodying human nature or even unfold opportunities for the improvement of humankind.

However, arguing about some specific definition of human nature seems to be a poor way to proceed. If there is any constant nature for human beings, it would need to include a desire for freedom or the desire to freely pursue possible new forms of life. In other words, freedom is at least one defining feature of all humans. Such a nothing-ness implies an open-ended future for the evolution of humankind and society.

Here I argue that if we see both engineering and human nature from the evolutionary perspective, the above-mentioned debates will be placed in a better context. Such a perspective helps us grasp opportunities for overcoming human limitations and improving physical and mental capabilities as revealed and made possible through technologies. In this sense, the issue is not so much about humanizing technology and engineering as about answering such questions as "What kind of being do we want to become?" and "How are human beings themselves to be reconstructed?

This argument is inspired by John Dewey, one of the greatest philosophers of the twentieth century. On occasion Dewey has been labeled as an experimentalist. My thought about engineering and technology has also been influenced by Bruno Latour, a distinguished French anthropologist and philosopher, who seems to have also been influenced by Dewey. The following argument will draw insights from these two sources, as well as others, to develop experimentally (tentatively) an experimental philosophy of engineering in which the conception of experiment will be at the core.

4.2 Two Paradoxes in Classical Philosophy of Technology

To express this view better, let me begin with a brief summary of some key ideas in classical philosophy of technology, with thinkers such as Martin Heidegger and Jacques Ellul in a core group. There are two paradoxes in their ideas.

The first paradox is about control of the uncontrollable. A main theme in classical philosophy of technology is that modern technology is "something completely different and … new" (Heidegger 1977, p. 5) and itself out of human control (Winner 1977). It is argued that technology operates according to its own autonomous logic, and that humanity is not capable of guiding the historical direction in which technology is taking us. As Heidegger writes: "No single man, no group of men, no commission of prominent statesmen, scientists, and technicians, no conference of leaders of commerce and industry, can brake or direct the progress of history in the atomic age" (Heidegger 1966, p. 52). So the task of thinkers is to find ways to regain control of technology or overcome domination by technology. Society needs to implement new measures, including new technologies, to control the uncontrolled.

Ironically, such a view may encourage more and more new technologies, with the new technologies out of control as well. Actually, "the will to mastery becomes all the more urgent the more technology threatens to slip from human control" (Heidegger 1977, p. 5), and all attempts to reckon existing reality in terms of decline and loss, in terms of fate, catastrophe, and destruction, are merely technological behavior (Heidegger 1977, p. 48). In like manner, Ellul (1964) recommends an all or nothing strategy to overcome the so-called technological phenomenon. But his tone is pessimistic, insofar as human beings seem to have to take all technologies if they take any of them, or to reject all of them if they want to be free. It is doubtful that this is a viable strategy.

At the same time, neither Heidegger nor Ellul are Luddites. They do not advocate return to a pre-technological world. To Heidegger, the danger of the all-embracing technological phenomenon is not the destruction of nature or culture so much as a restriction in our way of thinking—the technological understanding of being (Dreyfus 1995). Even if there is no destruction of nature or culture by specific technologies, and everyone is happy in all respects, Heidegger would remain concerned about the technological thinking of being. For him, the greatest danger of our technological understanding of being is the possibility that we will lose the capacity to understand ourselves in any other way. As he says, "the approaching tide of technological revolution in the atomic age could so captivate, bewitch, dazzle, and beguile man that calculative thinking may someday come to be accepted and practiced as the only way of thinking" (Heidegger 1966, p. 52). But he believes that "we can affirm the unavoidable use of technical devices, and also deny them the right to dominate us, and so to warp, confuse, and lay waste our nature" (Heidegger 1966, p. 54). In other words, it is possible for us to have technologies without the technological understanding of being. According to the interpretation of Hubert Dreyfus, Heidegger is "not announcing one more reactionary rebellion against technology", nor is he proposing "a way to get technology under control so that it can serve our rational chosen ends" (Dreyfus 1995, p. 97). Unfortunately, however, his fatalistic "substantivism" leads him to advocate liberation from the technological order rather than its reform (Feenberg 1991, p. 17).

At the end of "The Question Concerning Technology" (1977), Heidegger quotes Hölderlin's "where danger is, also grows the saving power", and elsewhere (in the posthumously published *Der Spiegel* interview), presents the danger of our epoch as the coming to presence of being through enframing, within which "only a god can still save us" (Heidegger 1976). What then is this saving (divine like) power? In this pluralized modern world, it could be argued that we should not expect and do not need god or one all-embracing community. Moreover, it seems that we cannot afford to wait when faced by the huge challenges that technology and engineering have brought with them. We must act now experimentally, democratically, and in decentralized ways.

More importantly, however, according to Bruno Latour, "in the realm of techniques, no one is in command—not because technology is in command, but because, truly, no one, and nothing at all, is in command, or to master, not even an anonymous field of force" and "To be in command, or to master, is a property of neither humans nor nonhumans, nor even of God" (Latour 1999, p. 298). In other words, technology is uncontrollable. If this is true, the attempt to control the uncontrollable will be a futile activity.

The second paradox, related closely with the first, concerns an opposition between human nature and technology. The classical philosophers have criticized modern technology for its domination of human nature. Ellul (1964), for instance, argues that human beings invent technology to serve their interests, but technology in reverse constrains or even deprives humans of freedom. Although technology should be in the service of humanity, it ends up doing humanity a disservice (Dreyfus 1995). Such situation has been described as one of alienation.

Could there even be humans without technology? Is there such a thing as a pre- or non- technological human nature? Karl Marx, for instance, in his *Economic and Philosophic Manuscripts of 1844* argues that all human action is engaged with technology, which reveals and embodies human nature. Nick Bostrom (2010) goes further and argues that technology unfolds opportunities for the improvement of humankind. According to Bernard Stiegler (1998), the genesis of technics corresponds not only to the genesis of what is called "human" but of temporality as such, and that history cannot be conceived according to the idea that humanity is the subject of history and technology simply the object; instead, the "who" and the "what" are in an undecidable relation. If we accept that humans invent technology, we should at the same time accept that technology invents the human. All artifacts have to some extent transformed the human actors who use them or are just influenced by them. Indeed, there are exchanges of properties between artifacts and humans (Latour 1999).

So, it is reasonable to argue that human beings are not just tool-making animals, but also tool-made animals. Therefore, if there is anything called human, it cannot be separated from technology. The pure opposition of human beings and technology is groundless.

Moreover, if there is any constant nature for human beings, it is better to say it is the desire for freedom or the desire to freely pursue life possibilities. Such a nothingness creates an open-ended future for the evolution of humankind and human society. With this understanding, humans are permanently in the process of creating and re-creating themselves, and engineering practices are very much the realization of human life possibilities.

4.3 Insight from Experimental Metaphysics

To cope with the paradoxes examined above, we need to take another step into experimental metaphysics, which will become a foundation for the experimental philosophy of engineering.

Dewey may have been the first to propose an experimental philosophy. He observes that the world is an admixture of the contingent aspects of things and the patterned regularity of processes that allows for prediction and human intervention. For him, a sound metaphysical description of reality must embody both of these elements of experiences (Dewey 1929). With this spirit, he criticizes both the judgment that history exhibits inevitable laws that are internally dynamic and the belief that history involves either single- or multiple-factor causal accounts (Hickman 1990, p. 159). Dewey's view of history is the foundation of the experimental spirit of engineering practices. It is through various experiments that we can deal with the surrounding world.

Latour expresses a similar view with more depth. Inspired directly by Alfred North Whitehead, Latour has articulated an experimental metaphysics. In his actor-network theory, actors are "not conceived as fixed entities but as flows, as circulating objects, undergoing trials" (Latour and Crawford 1993). Its core tenet is not to limit *a priori* who or which are the actors and their properties. In other words, nothing should be concluded in advance. It is this ban on *ex-ante* decisions that authorizes Latour to describe his metaphysics as the experimental in the sense that its conclusions are provisional and that it proceeds by way of various experiments (Miller 2013, pp. 12–13). Moreover, Latour assumes an irreducible metaphysical plurality which encourages proliferation of as many actors, be it human or nonhuman, as the universe can muster. For him, there is no original, pre-established ontological difference between subject and object, and between culture and nature. All objects, human and nonhuman alike, act on the same flat metaphysical plane. What differences exist in between are vague, constructed, and mobile. The result is that the world becomes "an immense, messy, and muddy construction site" (Latour 2004, p. 161).

Since one object is never reducible to another, actual work is needed to show the ways in which objects partly influence one another while remaining partly shielded from such influence. This process of relation-building is what has been called "translation". "Translation is necessary because objects resist transparent reduction. Translation is possible because objects, composed of and shaped by other objects, are available" (Miller 2013, p. 60). Therefore, any metaphysical, macro-account of change should be banned in order to localize responsibility in the multitude of objects that do the actual work of formulating the world's provisionally stable associations.

For Latour, the fact that we do not know in advance what the world is made of is not a reason for refusing to start off, because other storytellers seem to know and are constantly defining the actors that surround them. The analyst may begin at any point by recording what each actor says of the others. The only task of the analyst is to follow the transformations taking place among the actors convened in the stories (Latour 1988, p. 10). As a special kind of story-tellers, scientists are successful when they have "invented such dramatized experiments that the spectators could see the phenomena [they were] describing in black and white" (Latour 1988, p. 85). In so doing, the laboratory, a place where groups of normally diffused actors are gathered and aligned, is essential because it manufactures these previously inaccessible points of view. In this regard, the laboratory is a more suitable model for society than Michel Foucault's panopticon.

From such a perspective of experimental metaphysics, humans are inherently experimental. Human beings come to be, not as maturing fruits, but as perpetually incomplete events. As one explication of Latour frames it, human existence is a fateful rupture in the fabric of the world; humans can anticipate, can project themselves futurally, run ahead of themselves, only on the basis of the already-there of their inherited past (Harman 2007, p. 52). Latour himself asserts the point more forcefully, "It would be sinful to suspend the learning curve for good, even—or especially—in the name of intangible moral principles that would define humanity once and for all and without due process. Humanism, too, must become experimental" (Latour 2004, p. 198).

Within this experimental metaphysics, a new image of philosophy emerges: philosophy as an experiment. According to Dewey, philosophical enquiry itself can be regarded as an experiment, and its meaning lies in its making differences in the world. In this sense, philosophy is in no opposition to science. "It is a liaison officer between the conclusions of science and the modes of social and personal action through which attainable possibilities are projected and striven for" (Dewey 1929, p. 295). What we need is a humble philosophy. That is to say, everyone can be regarded as a philosopher; all people have their own philosophies and live in their own world. Professional philosophers may not be superior to ordinary people.

Surely, as a human endeavor, "philosophy is never a set of final true results, but always a brave and unpredictable foray into the concealed depths of the world" (Harman 2007, p. 51). What philosophy should be trying to do is to hint or point toward the depths of the world; in so doing philosophers can bring the world forth, give a new view of the world, and constitute the world experimentally.

4.4 Uncertainty and Experiment in Engineering

Now let us turn to engineering practice. In general, engineering practice is an experimentally constructive process, in which things and human beings are shaped and reshaped simultaneously. Such a process is inherently uncertain. There are two reasons: the behavior of actors involved in an engineering project cannot be completely predicted, and technologies used in the project cannot be fully controlled by any single actor. For Latour, due to the translation effects, the action is always overtaken by what it acts upon (1999, p. 298).

Uncertainty might be expected to decrease with the accumulation of knowledge. But while increases in knowledge may reduce some kinds of uncertainty, others arise. As Dewey observes, human beings have "never had such a varied body of knowledge in [their] possession before, and probably never before [have they] been so uncertain and so perplexed as to what [their] knowledge means, what it points to in action and in consequences" (Dewey 1929, p. 297). He makes it clearer in the following:

> At the best, all our endeavors look to the future and never attain certainty. The lesson of probability holds for all forms of activity as truly as for the experimental operations of science, and even more poignantly and tragically. The control and regulation of which so much has been said never signifies certainty of outcome, although the greater need of security it may afford will not be known until we try the experimental policy in all walks of life. The unknown surrounds us in other forms of practical activity even more than in knowing, for they reach further into the future, in more significant and less controllable ways. (Dewey 1929, pp. 291–292)

As a result, in transforming nature, humans, and society, engineering practice often raises economic, social, or environmental problems, even causes huge losses or even casualties. It is thus reasonable to take a more conservative attitude toward doing engineering than toward doing science. Indeed, in facing uncertainty, the oldest and simplest mental immune system simply commands "believe the old, reject the new" (Drexler 1986, p. 37). To make progress, however, human beings must turn to and rely on experiments. Dewey stresses the need for an open-ended, flexible, and experimental approach to problems of practice aimed at determining conditions for the attainment of human goods and a critical examination of the consequences of means adopted to promote them, an approach that he called the "method of intelligence." Also, Latour notes that "nothing can replace the experiment that must always be carried out without certainties" (Latour 2004, p. 199).

4.4.1 *Learning from Experiment*

Basically, an experiment is a procedure performed with the goal of verifying, refuting, or establishing the validity of a hypothesis. In some cases, the experiment may aim to answer a "what if?" question, without a specific expectation about what it will reveal, or to confirm prior results. The experiment can also be considered as a technical manipulation that determines certain features of a given product, process, or service in accordance with a specified procedure.

In engineering, various experiments simply extend the ability to imagine consequences, to make mistakes in thought rather than in practice. Engineers can evolve their hardware in the world of the mind and computation before filling in all the details of a design. Indeed, "enlightened trial and error, not the planning of flawless intellects, has brought most advances; this is why engineers build prototypes" (Drexler 1986, p. 31). When based on sound mental models, thought experiments can replace more costly, even deadly physical ones. Usually, engineers use mathematical laws to describe engineering objects and to test simulated designs before building them.

However, experiments are difficult, uncertain, and even risky. An experiment can be good or bad:

> A bad experiment is not one that fails, but one from which the researcher has drawn no lesson that will help prepare the next experiment. A good experiment is not one that offers some definitive knowledge, but one that has allowed the researcher to trace the critical path along which it will be necessary to pass so that the following iteration will not be carried out in vain. (Latour 2004, p. 196)

Historically, experimental methods have advanced considerably. For instance, in the aircraft industry, test pilots are employed to fly new or modified aircraft in specific maneuvers, known as flight test techniques, allowing the results to be measured and the design to be assessed. In the 1950s, test pilots were killed at the rate of about one a week, but the risks have decreased rapidly to a fraction of that, due to the maturation of aeronautical engineering, better ground-testing and simulation of aircraft performance, and lately, the use of unmanned aerial vehicles to test experimental aircraft properties (see "test pilot" from Wikipedia).

However, due to the residual uncertainties in engineering practice, we must seek help of further technical and organizational experiments. Much of engineering methodology and institutional arrangements have been developed in order to establish proper experimental spaces to facilitate various experiments and to prevent possible unintended disasters. This may be illustrated by China's experience of develeopment with extreme expansion of experiment space through the reform and opening up policy since the year 1978. China's former leader Deng Xiaoping once said,

> We should be bolder than before in conducting reform and opening to the outside and have the courage to experiment. We must not act like women with bound feet. Once we are sure that something should be done, we should dare to experiment and break a new path.… If we don't have the pioneering spirit, if we're afraid to take risks, if we have no energy and drive, we cannot break a new path, a good path, or accomplish anything new. Who dares claim that he is 100 per cent sure of success and that he is taking no risks? (Deng 1992)

Such words clearly apply to engineering. In fact, the quotation reveals a simple truth: experiment is the optimal strategy for humankind to cope with ignorance, and the precondition for development is to build up proper experiment spaces. However, we need to distinguish between the two types of experiments, the monopolistic and decentralized. The former is bold and large in scope, but precisely for this reason it limits the search space and repeatability; it reduces the probability of identifying successful organizations and sound technologies. In contrast, the latter allows a variety of trials, and in so doing empowers actors to search freely and broadly for good practices; this results in better chances for the whole society to learn about effective organizations and technologies. So decentralized experiment is the better approach to dealing with human ignorance, and is surely the symbol of an open society (Popper 1945).

4.4.2 Engineering Failure as Experiment

Although engineering is widely imagined to be a matter of studying a problem systematically and conceiving the best solution, the reality, as Henry Petroski (1985) explains, is that engineering efforts viewed in retrospect are more like hypotheses or good guesses at solutions. We build something that functions, and then see the shortcomings and learn from them for further improvements.

Petroski emphasizes that it is not possible to anticipate all possible ways a design can fail and thus failures inevitably occur because engineers are, after all, humans. He argues that understanding such design failures can advance engineering even more than successes. From this point of view, engineering failures should be embraced and learned from, rather than denied or ignored:

> No designer or engineer wants his or her machine or structure to fail catastrophically when it is being used. That is why engineers especially think about failure when designing their gadgets and systems. If engineers do not openly anticipate how failure might occur in what they are designing, then they may not think to incorporate into the design a defense against its happening. But no matter how thoroughly a design might be vetted for possible ways in which it can fail, there can be no assurance that some unforeseen circumstances might not produce some new and undesirable effect. There can be no assurance that the scale or ambition of the new devices, structure, or system has not taken it into an unknown realm, where physical phenomenon previously of not great significance begin to dominate performance and thereby precipitate failure. (Petroski 2012, pp. 267–268)

To Petroski, understanding failure is the only way to bring successful design and engineering into the future. Engineering does advance through failure, but only if the lessons that failure teaches are applied to future projects. He notes that “documented failures are among the most valuable experiences, because they reveal weaknesses in reasoning, knowledge, and performance that all the successful designs may not even hint at. The successful engineer is the one who knows not only what has worked in the past but also what has failed and why” (Petroski 2012, p. 37). Therefore, the greater tragedy in engineering is not having failures but of not learning the correct lessons from them.

So, the lesson is: Learn from failure, do not make the same mistake twice, but recognize that failure is an essential part of the process of engineering innovation. In his last prose-fiction *Worstward Ho*, Samuel Beckett wrote a wonderful line, embodying an experimental spirit, “Ever tried, ever failed. No matter, try again. Fail again, fail better.” This is the very soul of engineering, as well as of being human. We can learn from engineering failure as well as success, and transform the originally tacit, informal, and uncodified knowledge into articulated, formal, and codified knowledge. In this regard, engineering failure can be viewed as a special experiment, if the stakeholders can learn something positive through systematic analysis of the failure. Just as Francis Bacon put it, “There remains simple experience; which, if taken as it comes, is called accident, if sought for, experiment” (Novum organum 1620: 101).

4.4.3 Foresight as Collective Projecting

As the technology race quickens, new developments sweep toward us faster, and fatal mistakes would grow more likely. With foresight as collective projecting, we will have a better chance to steer engineering practices in safer directions.

According to nano-engineer Eric Drexler (1986), three questions—What is possible? What is achievable? What is desirable?—frame the foresight approach. It is what engineering communities can and should do collectively. To do this, Drexler proposes the conception of the “fact forum”, which is a process for seeking facts through a structured, arbitrated debate between experts. He describes the basic procedure as follows: Each side begins by stating what it sees as the key facts and listing them in order of importance. Through several rounds of argument, cross-examination, and negotiation, a referee seeks agreed-upon statements. Where disagreements remain, a technical panel will then write opinions, outlining what seems to be known, and what still appears uncertain. The output of the fact forum will include background arguments, statements of agreement, and the panel's opinions (Drexler 1986, p. 209). These procedures are open, credible, and focus on finding the facts on which we can conduct sound foresight.

With extensive participation of various stakeholders, foresight is framed to bring clarity to present action in light of desirably possible futures. Just as social scientist Ben Martin puts it, foresight is a "process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits" (Martin 1995, p. 140). Foresight in this sense is different from forecasting or prediction. The later presumes that there is a definite future for development of science and technology, and the society should passively adapt to the result of forecasting or prediction. In contrast, foresight presumes that the future is uncertain and there is more than one possible development path, and that the one to be realized largely depends on collective projecting and decision making.

So through foresight about science, technology, and society, human beings can collectively and more effectively harness science and technology to conduct superior engineering practices that can better serve the interests of the community, although the engineering development trajectory still cannot fully be predicted and controlled. As Dewey once wrote,

> Human desire and ability cooperates with this or that natural force according as this and that eventuality is judged better. We do not use the present to control the future. We use the foresight of the future to refine and expand present activity. In this use of desire, deliberation and choice, freedom is actualized. (Dewey 1922, p. 313)

4.5 The Co-evolution of Human Beings and Engineering Through Experiments

Based on the above, the co-evolution of human beings and engineering through experiments can be roughly sketched out.

As we know, for many classical philosophers of technology, there is a huge divide between the modern and pre-modern era. It seems that, with the advent of modernity, a transformation of relationship between human beings and technology emerged in which technological revealing started to define our modern way of living and human beings was helplessly thrown into the state of alienation. According to Latour, however, such a divide does not exist and the continuity of history reigns, because "we have never been modern" (Latour 1993). If there is something different between technologies in pre- modern era and those in modern era (if we can still use these terms), it is quantitative rather than qualitative, with more and more actors being mobilized, translated from one to another, and gathered into actor networks. In this way, with the development of science and technology, the human has been destined to step into the risk society, which means that we are "living on the volcano of civilization", with people's awareness of risk dramatically increasing, and experts losing the trust of the general public to a large degree (Beck 1992).

That is to say, alienation is the fate of mankind. In reality, from the perspective of experimental metaphysics, the human is by definition a kind of alienation, so that any specific definition of human nature would be a dehumanization. If there is any constant nature for human beings, it is simply the desire for freedom or the desire freely to pursue possible ways of life. In this sense, the human is in a state of permanent evolution, in which experiments plays an essential role. In other words, freedom is one defining feature of human beings, and the true life is experimental.

So, what is the relationship between technology and human freedom? According to Dewey, successfully exercised technology, as effective control of the environment, generates increased freedom because it "enlarges the range of action, and this enlargement in turn confers upon our desires greater insight and foresight, and makes choice more intelligent" (Dewey 2008, p. 104). Yes, technology and engineering may constrain human freedom in certain respects, but overall it magnifies freedom. Moreover, we should remember the saying, "No pain, no gain". For example, you cannot travel in safety without following some disciplines (which Michel Foucault might condemn). Thinking about the Second Law of Thermodynamics, does it not imply that we must lose something for the sake of something we desire much more?

Such a situation is much like the magnify/reduce relationship elaborated by Don Ihde (1979). For him, any technology both magnifies and reduces at the same time. His example is that the lunar surface viewed through a telescope is wondrously detailed, but the moon in its context of the night sky is lost. However, with this new restricted freedom to view the surface of the moon in detail, humans are also free to choose when and when not to use it. This model can be transformed to clarify the impact of technologies on human freedom. Overall, a sound philosophy of technology and engineering must accept the ontological identity of technology and human nature.

In fact, the very dynamics of the evolution is alienation itself. Alienation entails there being a gap between achieved results and some original goal. Such a deviation arises from the limits of human rationality, and points again toward the fact that human beings cannot take full control of the world around them. Surely, alienation is inevitable, and yet without alienation, there would be no evolution. Evolution depends on actions having unintended results from which selection can then be made. Alienation is not always a bad thing. It is the source of creation, a generator of problems, and a source of "alternative" solutions in both nature and technology. Indeed, technology is woven into social reality as well as at the organic level; it is part of the human as both a physical and a social entity. In this sense, reconstruction of the technical and of the people is closely related, and any critique of technology and engineering will also be a kind of criticism of the social and of any particular instantiation of the human. What is needed is not so much to criticize technology alone as to criticize the human-society-technology associations.

So we can clarify the relationship between engineering and human nature from the evolutionary perspective, which will help us grasp the opportunities of overcoming human limits and improving the physical and mental capabilities of human beings that technologies open up (Bostrom 2010). In this sense, the issue is not about humanizing technology and engineering; rather, it is about answering such questions as “What kind of beings do we want to become?” and “How are human beings themselves to be reconstructed?”

Freedom is the root of both humans and their technologies. If science and technology open up new possibilities for humankind, engineering practice seeks to realize the possibilities that deserve to be pursued. The motivation behind science, technology, and engineering is the human desire for freedom. In the West this understanding of the central value of freedom is often based on divine revelation and guaranteed by the idea of the human as created in the image of God. In Chinese culture, freedom has different, this-worldly foundations, and has been promoted as fundamental and the highest pursuit of Daoism. Insofar as the pursuit of freedom is fundamental to mankind and science and technology enact this freedom, any alleged opposition between two cultures (the sciences and technologies versus the humanities) is superficial. No freedom, no humanity; and no freedom, no science, technology, or engineering.

At the same time, with the development of science and technology, the space of experimentation has been undergoing tremendous changes. Historically, experiment space expanded greatly with the emergence first of the academic laboratory and then of the industrial lab. During this same period, the scale and scope of engineering-related communities have been expanding, with more and more actors becoming involved. As stakeholders, the public, has also entered into a dynamic relationship with experimental processes, and has become increasingly involved in engineering practice and evaluation. Insofar as this is the case, it has promoted a trend toward the democratization of engineering practice, and helped to eliminate possible problems in advance. In effect, this will involve collectively identifying new possibilities of existence and creating new life styles and a better home for human beings.

There is a co-evolutionary process at work here, a process in which things, human beings, technologies, communities, and society at large are mutually reconstructed. Since the dawn of the modern era, the experimental rule and the shaping of the sociotechnical experiment space have become important political affairs. In fact, a variety of institutional arrangements have evolved to help build up proper experimental spaces in which unintended outcomes could be collectively identified and moderated.

What to construct, how to construct it, how to do experiment, and how to delimit the experimental space: These all need to be determined by the communities around and across engineering projects. In such a collective foresight and experiment, the promotion and preservation of communicative reason (Habermas 1979), in addition to instrumental reason, is required. Such a reason is construed in terms of the noncoercive intersubjectivity of mutual understanding and reciprocal recognition (rightness, truthfulness, and comprehensibility), and provides a relatively valid foundation on which social consensus can be reached.

4.6 Conclusion

Engineering practice is a constructive process, in which things and human beings are mutually shaped and reshaped. Such a process inherently involves uncertainty, because the behavior of actors in an engineering project cannot be completely predicted, and the technologies used in a project cannot be fully controlled by any single actor. Due to such uncertainty in engineering practice, we must seek help from technical and organizational experiments. How to determine the scope and size of the experiment is a key issue, since we all want to avoid irreversible catastrophic outcomes.

An experimental philosophy of engineering is needed to make clearer the relationships between technology and the human condition. Engineering researchers and practitioners have to produce knowledge and experience from experiments, and so to build up the relevant conditions for beneficial engineering practices in the real world. In this sense engineering practice itself can be regarded as a kind of experiment. Learning from experiments is essential for human beings to survive and flourish. Human beings are permanently in the process of re-creation, and engineering practice is very much a part of the realization of new possible lives for humankind. As human beings, we have all led an experimental life, and indeed, we should continue.

Learning from the past, we look forward. We cannot return to the past, but have to look forward and experimentally, collectively, create our common future. In this regard, we have to make use of what Dewey called the “method of intelligence”. This is a process of co-evolution among humans, artifacts, and engineering practices. Beneath such a process is the pursuit of freedom. Moreover, designing the experiment space has become a political affair; the expansion and improvement of democracy is essential to deal with problems resulting from engineering practices. So to paraphrase René Descartes’ “I think, therefore I am” and Li Bocong’s “I create, therefore I am” (Li 2002), I would propose: “I experiment, therefore I am”.

One last point: from such a perspective, it seems that only one sort of future is broad enough to be desirable: an open future of liberty, diversity, and peace (Drexler 1986, p. 232). It is such a social order that can promote the intelligent adaptation of engineering practice to inevitable changes in the physical and social environment. So any solution to technology and engineering issues must also be founded on universal democracy. Just as Dewey’s saying, “Democracy and the one, ultimate, ethical ideal of humanity are … synonymous” (Dewey 2006, p.128).

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Chapter 5
Feasibility and Acceptability in Engineering

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Abstract Engineering involves systematic, complex, socio-technological activities, with both benefits and risks for the public. Most feasibility studies focus on the technological, economic, and material (resources and power) aspects. However, this ignores public acceptability and can give rise to public resistance and non-cooperation, which in turn undermines credibility of the government, enterprises, engineers, and technicians. As a result, some engineering projects are impeded or forced to relocate at huge costs in natural and financial resources. In light of such situations, it is necessary to incorporate acceptability studies into engineering feasibility studies. From the perspective of socio-technical systems, we first analyze the deficiency in feasibility studies and point out that as a concept, feasibility involves not only the instrumental aspect of practice, but also ethical and cultural dimensions. Then we argue that feasibility also connotes acceptability. On this basis, feasibility is revealed to presuppose social legitimacy, which is not the same as simple acceptance, but involves a synthesis of facts and opinions. Finally, through the examination of multiple-value conflicts and the public's limited understanding of engineering, we suggest that feasibility studies should be set in specific cultural contexts and follow problem-solving procedures that involve democratic negotiations or forums.

5.1 Introduction: Posing the Question

As Typhoon Meihua battered China's east coast on August 8, 2011, a dike protecting the largest Chinese manufacturer of Para xylene (PX) – a chemical used to make polyester products – was washed away. This accident allowed a backflow of

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seawater into the factory, left 700,000 tons of storage tanks in jeopardy, and resulted in PX leakages. Though the risk of a dam breaking was contained and no trace of dangerous chemicals was found, safety fears and anger were triggered among people in the city of Dalian where the industrial plant was located. A week later, on August 14, tens of thousands of Dalian citizens gathered in front of the municipal government offices to express opposition to the PX project.

This was the first open protest against a large-scale engineering project in China. Neither the government nor the manufacturer expected such a public reaction. In order to ease public upset, the Dalian municipal government promised to move the chemical plant out of Dalian. Similar protests have occurred in other parts of China in relation to other industrial projects. Examples include a protest in Xiamen, Fujian Province, in June 2007, and another in Ningbo, Zhejiang Province, in October, 2012. Many cases have, as at Dalian, interrupted production or forced relocation and caused enterprises and local governments serious economic losses.

Although these events are in the past, they present important issues. The protests not only reveal growing public concerns in China about industrial projects, they also throw light on questions related to engineering decision making and fundamental problems in engineering philosophy and ethics. As such, they can stimulate research on, among other concerns, how to understand engineering feasibility and risk acceptance.

5.2 PX Project and Dimensions in Feasibility Studies

Para-xylene (or PX) is an aromatic hydrocarbon compound in the form of a colorless, transparent liquid. It is mainly used in industry to produce plastic, polyester fibers, and thin films for numerous applications in life. PX is not regarded as dangerous based on its potential damage or risk. On the contrary, among the many products of the petrochemical engineering industry, it is considered quite safe. Many countries, including the United States and Australia, do not define PX as a dangerous chemical. The International Agency for Research on Cancer (IARC) labels PX as a Group 3 carcinogen, i.e., with no evidence suggesting PX is related to carcinogenesis. According to the national occupational health standards of China, the maximum allowable concentration for PX is even higher than that of acetic acid or urea, which means at the same concentration, PX causes less health risk (Zhang 2014). Obviously, the public did not perceive things the same way as the experts with regard to PX safety issues. Government and business enterprises failed to incorporate public understanding and public opinions into their feasibility studies.

Officially released information shows that in December 2005 the Dalian PX project was approved and certified by the National Development and Reform Commission (NDRC). Construction began in October 2007, and operations commenced in June 2009 with the approval of experts who had assessed location choice, argumentation, evaluation, certification, construction, and production. Chen Zhenggao, the governor of Liaoning Province, Zhang Chengyin, the municipal party secretary of Dalian, and Xia Deren, the mayor of Dalian, all visited the factory for field inspections. In the 2007 government report (People's Government of Liaoning Province 2007), Xia Deren described the Fujia Dahua PX project as an important achievement, one that would contribute to Dalian's efforts to pursue economic structural adjustments and developed new types of industries. All evidence suggests that the public was not excluded from information on the PX project. The Dalian Municipal Design and Research Institute of Environmental Science (DMDRIES) declared that the project location and the safety distance were determined by undertaking environmental impact assessments and were approved by experts through careful, scientific calculations, and repeated review. The DMDRIES also claimed that "the location of Dalian PX Project is decided with reference to precedent cases and is in line with the standards of national environmental assessment" (Chen and Wang 2011, p. 16). The fact that the PX project led to serious problems as far as the public was concerned implies that the paradigm for feasibility studies was inadequate.

"Feasibility studies" using this term can be traced back to the 1930s and engineering work done in the United States to explore dam construction and electrification in the Tennessee River Valley. But the notion of feasibility as central to engineering has a deeper history. Whereas science studies the world that is, in terms of theoretical possibility and necessity, engineering focuses on what might practically come to be, through the intervention of humans. Engineering thus opens, between possibility and necessity, a distinctive realm of artifactual functionality that has come to be called feasibility. For instance, the engineer rejects as impossible, the concept of a perpetual motion machine while seeing nothing like the necessity of gravity in the steam engine. Precisely insofar as the steam engine is possible but not necessary, engineering works to conceive and make it feasible, understood in the simplest sense as practical or successful. The successful engine or other engineered artifact works to achieve some desired end.

The first mechanical engineers studied the feasibility of heat engines in functional terms such as thermodynamics. However, over time, as it became increasingly the case that successful engineering depended on more than strictly technical factors, feasibility studies have expanded to include economic, legal, operational, and scheduling feasibility – and feasibility has become more a business practice than one of engineering method. The acronym TELOS, which is sometimes used as a mnemonic for technical to scheduling feasibility, nevertheless emphasizes the foundational character of the technical, so that there are issues both about the extent to which engineers rather than economists should be the managers of feasibility studies as well as the extent to which feasibility should be expanded further to include social, cultural, and other factors.

In the late 1970s, feasibility study was introduced into China and soon became a major method to evaluate the strengths and weaknesses of engineering projects with objectivity and rationality. In the Chinese context, feasibility study generally includes research on market demand, technological advancement, and economic rationality. So clearly, in this sense, feasibility refers to a comprehensive and systematic analysis and scientific examination of the potential technological advancement and economic results of a project, with a goal to maximize both. Due to the growth of the environmental movement, since the 1990s environmental and energy issues have also been included in the scope of feasibility studies. In general, current Chinese feasibility studies cover at least the four following dimensions: (1) the preconditions in terms of technology or knowledge, including infrastructure and software; (2) economic investment, returns, and risk; (3) environmental costs; (4) the supply of resources, including energy. The main concern of all the dimensions in feasibility studies is technological and material/economic (Wang 2014).

It is obvious that this feasibility study paradigm involves only the conditions of engineering on the natural, material, and technological aspects, i.e. the immediate objects of engineering. When knowledge about engineering is also included in the discussion, subjects or people are also involved. The problem is that this type of feasibility study paradigm only includes engineers and technicians as the subjects, excluding other interested parties, such as those who will be impacted by the project. The public, both as tax payers and the bearers of engineering consequences, are excluded from the discourse. In other words, engineering is seen as an activity within the engineering community per se, irrelevant to a larger public.

In fact, in a broader sense, engineering is a systematic activity that involves interest- related parties of all sorts. According to German Philosopher Gunter Rophol engineering activity is a social-technological system activity. "Technological activities refer to the ones relevant to production and usage of human-made products" (Wang et al. 2007, p. 80). Both users and consumers of technology, as well as direct/indirect users and the public, share equal status as co-subjects with technicians and administrative staff. Its processes and social impacts presuppose the participation of members of these groups. Based on this understanding of engineering, feasibility studies need to consider the multiple-values of multiple subjects, especially the values of stakeholders who have to live with the results. This is particularly important when the interests of the public conflict with those of the engineering community.

Technology is more than a simple material object. It is a complicated system of objects, humans, practices, and meanings instead of a mere assembly of mechanical and electronic equipment (Zhu and Wang 2010). Engineering design often embodies people's needs, goals, and interests, i.e., the engineering product contains values initself. The subjects of engineering consist of engineers as well as the users and consumers of the products. Feasibility in concept suggests effective understanding (reason, instrumental rationality) and also an appeal for legitimate norms and social acceptance. Feasibility implies, first of all, realistic possibilities with conditions, and then, being reasonable, appropriate, and legitimate (Wang 2011). Second, the engineering standard for feasibility involves effectiveness, which involves the public in terms of acceptance and expectation. In this sense, to look into feasibility means to consider the complementary stands and points of view from all involved parties. After all, we need to understand for whom any large-scale project is feasible. Is it the politician, entrepreneur, engineer, or public? People may have different views depending on their respective interests.

Seen from this perspective, the subjects of the Dalian PX project are not merely government and enterprises. The local people may have concerns about the environment and worry about the risks, even if the experts judge these to be irrational. What finally drives popular opinions and beliefs are questions such as “Will the PX project threaten their lives?” or “Will they be in danger”? When it comes to engineering feasibility studies, “modern engineering is an integrated system of both technological factors and non-technological factors”, and “the latter actually makes up the boundary conditions for engineering” (Yin 2008, pp. 5–6).

5.3 Acceptance and Acceptability

It is obvious that one of the most important reasons why Dalian PX Project ended up facing public resistance and protest is that engineering designers and constructors paid more attention to technological and economic factors than issues of public acceptance and acceptability. Beside the reasons mentioned above, the exclusion of considering the issue of public acceptance can be attributed to a sense in the engineering community that the public lacks genuine, relevant knowledge. Indeed, public acceptance of technology is usually determined more by experience than knowledge; public opinions can be irrational and inclined toward being guided or manipulated. That’s why in the Dalian PX Project case, experts, entrepreneurs or government officials have not taken public opinions into consideration.

At the same time, the acceptance-acceptability relationship is more complex than is often appreciated and cuts across the public-engineering divide. A general judgment concerning the acceptability of engineering does not justify assuming that any particular technological or engineering project will be accepted. Although it is often argued that values cannot be derived from facts, the importance of the converse needs to be recognized as well: that facts cannot be derived from values. With reference to the present case: not only is it true that the acceptability of technology (as a value) cannot be derived from its acceptance (whether by engineers or the public) but the acceptance of technology (as a fact) cannot be derived from any inherent acceptability (as a value held by either engineers or the public). Because experts and public often hold different values, their points of view on what should be accepted are quite divergent.

German philosopher Hubig has also noted a distinction between acceptance and acceptability. For Hubig, “acceptance in general implies the acknowledgment of the goals to be realized” (1997, pp. 264–266). Acceptability, by contrast, involves acceptance justified or capable of being justified. This means that acceptance as a fact cannot forcefully defend the rightness of engineering projects, and non-acceptance does not necessarily suggest the unacceptability of projects. But this distinction should not be interpreted as a reason to reject or deny the integration of public acceptance into feasibility studies. On the one hand, it connotes empirical content, perhaps even measurable criteria, so that whether or not a technology has been socially accepted appears to be a decidable question, a matter of fact about social relations or how things stand in the world. On the other hand, the phrase “social acceptability” suggests a normative judgment in a way that makes social acceptance involve inherently contentious characterizations of "society's values" (Thompson 2001).

Public acceptance is affected by multiple factors. One is how the public perceives engineering safety. As a concept, safety covers more dimensions than mere engineering. It not only has objective standards based on safety norms or criteria, but also relates to people's perception. From the perspective of technological risks to public health, Bernard L. Cohen (1985) examines the acceptability criteria for technology. Is it the average number of deaths per year technology causes, or the potential for events of low probability yet grave consequence? For the public, the latter criterion has a strong tendency to take priority over the former. However, Cohen argues that in a general sense, nuclear power is more acceptable than coal-fired electric power plants on the basis for the former. Even the anti-nuclear power activists concede that coal-fired power plants in fact regularly cause deaths among miners and those exposed to coal pollution; For Cohen, France is more rational in its acceptance of nuclear power than that of Germany, where it will be banned by 2022.

This points to another factor affecting public acceptance of technology: culture. Culture is an especially obvious factor in the field of biological technology, with the European Convention for the Protection of Human Rights and Dignity of the Human Being with Regard to the Application of Biology and Medicine: Convention on Human Rights and Biomedicine as a good example. Dieter Birnbacher (2009) notes that although European people to some extent share a common culture, they still harbor different attitudes toward bio-tech. Additionally, public acceptance of technology relates to public trust in experts and government. Harry J. Otway examines the development of "acceptable risk", and then points out that increased risk awareness leads to growing public mistrust of experts who are supposed to safeguard them from technological risks (Otway and Winterfeldt 1982). Increasing risk awareness triggers concerns about how effective regulations are when based on consensus among experts. One result is that public interest groups begin to seek education and advice from independent experts, and an open display of conflicting opinions from experts further undermines public trust in experts.

Finally, public acceptance further depends on technological channels for information communication. In an age of virtual technology, information can be communicated in various ways with some products promoted in the name of high-tech, and others anonymously releasing irresponsible information on the internet and causing public panic. When conventional sources and the process for decision-making are neither transparent nor accessible to the public, people are easily influenced by false information. In the protests against PX, the earliest reports spread via social media. Weibo (Chinese twitter) and WeChat were full of sensational and misleading information like "PX is as dangerous as a nuclear bomb", or "The explosion of PX storage tanks may release power as great as that of more than 100 nuclear bombs", or "According to national regulation, the site of the PX factory should be located at least 100 km away from urban areas. Dalian PX project is only 20 km away." The public was horrified by the information promoted by social media, which is one justification that the Chinese government gives for controlling of social media more than is practiced by governments in the West.

Compared with factual acceptance, the value dimension in acceptability lies in its rightness – including rightness in legal and moral terms. The minimum acceptability in law is to do what is legal. If an engineering project is forbidden by law, it is then neither acceptable nor feasible. For example, a project of potential serious environmental pollution is not feasible in law if its discharge of pollutants or disposal of waste cannot meet the Environmental Protection Act. New and large-scale projects usually involve many different areas and inevitably relate to the culture of their surrounding environments. Activities are always carried out in specific social and cultural contexts. Therefore, full consideration and respect should be given to context and social and cultural values, including religion, custom, and any other relevant local cultural beliefs. If a project is not feasible in a cultural context, then when it is carried out, it will have potentially serious consequences and costs in the future. In terms of morality, the acceptability of engineering involves justice and core values such as human rights and freedom. As John Rawls (2009, p. 3) notes, "Each person possesses an inviolability founded on justice that even the welfare of society as a whole cannot override."

5.4 Feasibility Decision Making Based on Acceptability

To study engineering feasibility, it is important to make a distinction between acceptance (as a fact), and acceptability (as a value). Acceptance (as a fact) is affected by experience that involves factors of culture, emotion, beliefs, trust and etc. The public resistance to PX can be seen as coming somewhat out of fear that PX might contain poisonous carcinogens. In fact, PX has very low toxicity and has yet to be shown to be carcinogenic. Irrational fear may also result in a "Not in My Back Yard" (NIMBY) attitude that can lead the public to reject building a factory even when it is acknowledged that PX has little risks.

In the present case, facing strong public opposition, a declaration was made that the Dalian PX Project would cease production and be relocated. Though public anger was eased, this might not have been the most rational decision nor in the best interests of the local population, considering the huge economic loss to the community. Hasty compromises made by the governments of Xiamen and Dalian also led to stronger resistance to PX projects in other places in China, such as in Ningbo and Kunming. As a result, the price of PX is on the rise in the international market and presents the chemical industry with special challenges.

It is clear that it is important to study the factors needed for public acceptance and the necessary conditions for its acceptability. One of the conditions is the public acceptive capability that plays an important role in decision making on what should be accepted. The acceptive capability is a rationality to synthesize and analyze empirical facts and information, and also to make justified and right judgments about values. Acceptability for large-scale technology depends on various factors, some being security and economically based, while others are of cultural, social, and psychological significance. Acceptance of risks is based on the information that people are exposed to, yet, what people choose to believe is still guided by the values they hold. These values are inherent in acquired social experience, dynamics of stakeholder groups, vagaries of the political process, and the historical situation into which technologies are introduced (Otway and Winterfeldt 1982). Rational decisions can take into account the irrational factors, yet should not be controlled by them. Amartya Sen (2006, p. 19)believes in Consistent Rationality and that rational actions must be consistent, i.e., a choice being consistent with its end. In the case of Dalian, the PX project was approved for economic interests. When it had to relocate under public pressure, the Consistent Rationality Principle was undermined, since the government made the choice out of public expectation for environmental benefits. The intended action, controversial or not, already presupposed the acceptance of anticipated risks according to this principle.

Decision-making on the Dalian PX project shows that both the public and government acted against the Consistent Rationality Principle that requires people to see potential risks in any technology. To choose a technology is to choose a lifestyle. In the case of Dalian PX Project, the local government and enterprises needed to make more active efforts to inform the public via all possible communication channels of both the opportunities and risks that the project would entail. Government has the responsibility to consider public concerns when making decisions, rather than to make hasty one-sided decision and then compromise after encountering opposition. In other words, decisions based on acceptability should be made with wide public participation that includes all stakeholders, on the condition that all participants should act according to Consistent Rationality.

In this sense, the ethics of technology is enlightenment that helps the public have full understanding of the values of technology. Besides, as a means to put across relevant knowledge of the science and technology, enlightenment could also help the government, engineers, enterprises, and public communicate better and give the public the ability to make sound decisions concerning technologies.

5.5 Conclusion

In the case of the Dalian PX Project, neither local government nor enterprises fully considered or respected the public in terms of their positions, attitudes, and choices when engineering feasibility decisions were made. The reason lies in the deficiency of understanding of both engineering feasibility and acceptability as more complex concepts than is commonly appreciated. Facts show that engineering feasibility relates to material and technological factors, decisions of engineers and administrators, and public acceptance and acceptability as well. So we suggest that feasibility studies should be set in specific cultural contexts and follow problem-solving procedures that involve democratic negotiations or forums. In conclusion, feasibility study of engineering projects should pay more attention to the acceptability of engineering.

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Chapter 6
Ancient Chinese Attitudes toward Technics: Chinese Philosophy of Technology Prior to the 1800s

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Abstract Chinese scholars began to reflect on technics and technology during ancient times. The earliest effort in recorded history is the *Yijing*, which has been attributed to the Western Zhou dynasty. What was originally a book of divination also contains philosophical reflections on technics which have influenced views of later generations. The philosophical traditions of Confucianism and Daoism have also contributed to Chinese philosophy of technics and technology, although they tended to promote opposing attitudes. In addition, there are influential practical texts such as two technical manuals, the *Kaogong ji* and *Tiangong kaiwu*. Summarizing from all these sources, three key ideas that distinguish Chinese from Western thinking about traditional technics and eventually modern technology are the absence of a Creator god (or, more positively, a sense of the material world as self- subsisting), an emphasis on practice (and the primacy of practical or political affairs in human life), and a concern for harmony between heaven and earth (that is, between human beings with the larger world in which they live).

6.1 Introduction

Like many domain-specific subfields of philosophy, such as the philosophy of physics or the philosophy of economics, the philosophy of technology is a comparatively young field of investigation in both the East and the West. In China the philosophy of technology did not begin to be pursued as such until the 1980s. Nevertheless, there is a Chinese prehistory of the subject stretching back millennia, with a heritage that is as long and rich as in the West. More specifically, the earliest period of philosophical reflection on the nature and meaning of making and using physical

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artifacts arose spontaneously and independently at roughly the same time in ancient China and in classical Greece.

However, Chinese systematic reflective thinking on the nature and characteristics of making and using artifacts has its root in a very different natural, economic, and social way of life than in the West. First, geographically China is a continental country, which has vast territory and abundant agricultural resources. That over 95% of people worked on farms created a closer connection with nature. Second, artisans—one of the four classes of people (the others being scholar, farmer, and merchant)—may have been ranked below those who supported the agricultural economy, but were not as low as in the West. Third, "in technological influences before and during the Renaissance China occupies a quite dominating position" (Needham 1969, p. 58). A great number of technical achievements can be attributed to the Chinese. Finally, in China, philosophy is much more ethical and social in orientation than metaphysical. Chinese philosophy was never pursued by as small an elite and focused so strongly on theory as tended to be the case in the West. For these three reasons, among others, ancient Chinese attitudes toward technics exhibit distinctive characteristics.

This paper will introduce some important contributions to this theme, including not only Chinese philosophers of different traditions and their theories, such as Confucianism and Daoism, but also some non-philosopher historians, scientists, artisans, and officials and their works. Among the works to be highlighted are the *Yijing*, *Kaogong ji*, and *Tiangong kaiwu*. Finally, a conclusion will offer some general reflections.

6.2 易经*Yijing*: A Basic Source of Chinese Attitudes Toward Technics

The *Yijing* (Book of changes) is one of the earliest books in China and the world. Most Chinese scholars agree that it originated as a composite work of divination texts by more than one person during the late period of the Western Zhou dynasty (1046–771 BCE).

The *Yijing* is structured around 64 graphic symbols known as hexagrams that are composed of 284 broken and solid horizontal lines. In part because the book was traditionally attributed to the ancient sages being informed by the natural world through spiritual intelligence, these symbols came to be interpreted as natural cosmological principles. The British sinologist and historian Joseph Needham thought the *Yijing* mathematically expounded the inextricable link between the individual and the cosmos. In his words, "While the Pythagorean school flourished (600–300 BCE) the scholars and diviners of China were developing the *Yijing* into a universal repository of concepts which included tables of antinomies (阴阳 *yin yang*) and a cosmic numerology; all this was systematized in the Han" (Needham 1954, p. 228).

Since ancient times, the Chinese have viewed the designing and making of artifacts as a kind of human activity that depends very much on the interaction between humans and the cosmos or nature, and thus must be guided by the principles of the *Yijing*, which is regarded as an ancient source for guidance on the designing and making of things (Zhao 2004, p. 85; Gao 2004, p. xxviii). Two ideas in the *Yijing* that became especially influential over time are 道 *dao* and 器 *qi*. First, both *dao* and *qi* are equal in value. *Dao*, according to Chinese philosopher Feng Youlan, refers to principles that govern each separate category of thing in the cosmos, and might be described as "universal" in Western philosophy (Feng 2007, p. 274). *Qi* refers to a specific expression or material form of *dao*, in both natural and artificial things. Regarding their relationships, for the *Yijing,* "that which is antecedent to the material form exists … as an ideal method, and that which is subsequent to the material form exists … as a definite thing" (appendix III, sec. 1, ch. 12, 78; Legge trans. 1882, p. 377).

Dao always exists beyond specific things and also is their natural law. *Qi* usually is determined by *dao*; it is through *qi* that dao is known. Therefore, the human activity of designing and making is not subordinate so much to thinking and learning; instead designing and making can become avenues in themselves for acquiring knowledge and wisdom. Additionally there is the notion of 制器尚象 *zhi qi shang xiang* (inventing or making artifacts by modeling or imitating images). According to the original explanation in the *Yijing,* "We should set the highest value ... on its [characteristic of the way of the sages] emblematic figures for (definite action as in) the construction of implements" (appendix III, sec. 1, ch. 10, 59, Legge 1882, pp. 367–368).

It means that the only way for a sage or artisan to design and make artifacts is by modeling emblematic figures. What is an emblematic figure? In the *Yijing* the sages, on the basis of their observations and thinking about the natural world, identified what they perceived to be fundamental characters in all natural things.

> (The sage) was able to survey all the complex phenomena under the sky. He then considered in his mind how they could be figured, and (by means of the diagrams) represented their material forms and their character. Hence those (diagrams) are denominated semblances. (appendix III, sec. 1, ch. 12, 79; Legge trans. 1882, pp. 377–378)

The *Yijing* thus considers emblematic figures as archetypes for artifacts in much the same way that Plato argued for ideal forms as the cause of particulars. Both the Platonic ideas and the *Yijing* emblematic figures are to be referenced by humans in order to understand natural phenomena or fabricate artifacts. But whereas Plato's ideas are grasped by the intellectual soul (and, in Christian Platonism involve a belief in God) the *Yijing* emblematic figures are comprehended through observations of the natural world by humans.

However, the emblematic figure alone is not sufficient for the making of artifacts. According to the *Yijing*, artifacts are organic unities of humans and nature, and more specifically, of the three powers (天 *tian* heaven, 地 *di* earth, and 人 *ren* humans).

> In ancient times, when the sages made the *yi*, it was with the design that (its figures) should be in conformity with the principles underlying the natures (of men and things), and the

> ordinances (for them) appointed by (heaven). With this view they exhibited (in them) the way of heaven, calling (the lines) *yin* and *yang*; the way of earth, calling (them) the weak (or soft) and the strong (or hard); and the way of humans, under the names of benevolence and righteousness. (appendix V, ch. 2, 4; Legge trans. 1882, pp. 423–424)

The "three powers" represent the ancient core idea about the harmony between the heaven and humans, also known as favorable climatic, geographical, and social human conditions. This idea had wide influence on different fields in premodern China, such as the military, agriculture, handicrafts, and medicine. One of the manifestations of the "three powers" is the principle of "four elements" (heaven, earth, matter, humans) in the *Kaogong ji* (Fan 2005, p. 119), which contains the earliest systematic and basic Chinese views of technics.

6.3 考工记 *Kaogong ji*: Earliest Chinese Text on Technics

During the Spring and Autumn and the Warring States periods (770–221 BCE), when slavery ended and feudalism was established, the handicraft arts flourished and the earliest Chinese text to deal with technics appeared. This was the *Kaogong ji* [Records of examination of artisans], an official book of the Qi state composed by an unknown author. The *Kaogong ji* describes manufacturing processes and specifications for carpenters, metalsmiths, leather workers, dyers, jewelers, and potters. Along with the *Tiangong kaiwu* (to be considered below), it is a classic for research on the Chinese history of technology (Wen 1993, pp. 1–2; Needham 1954, p. 111).

A similar text in the West is the *Diversarum schedula artium* [List of various arts] or *De diversis artibus* [On various arts], which was compiled in Latin probably between 1100 and 1120 CE by Theophilus Presbyter (flourished 1070–1125). Not only did the Latin volume not appear until 1500 years later than the Chinese one, it is quite different in content, paying little attention to manufacturing techniques related to daily life. Instead it focuses on detailed descriptions of various medieval religious arts, such as the production and use of painting and drawing materials (painting techniques, paints, and ink), the production of stained glass and techniques of glass painting, and various techniques of goldsmithing and other metalwork, even the building of organs.

By contrast, the *Kaogong ji* makes general comments on how to make things. To this extent, it is not just a handbook for technics but provides something akin to a philosophy of technology (Li and Liu 2005, p. 50). In regard to the nature of making artifacts, for the *Kaogong ji*, "All the artifacts that made by 百工 *baigong* [the general name for all kinds of artisan and the handicraft industries] are the invention and creation of the sage" (Wen 1993, p. 4).

At first glance, these words might be misleading. The Chinese idea that all things are invented and created by the sage alludes to history; as mentioned earlier, the *Yijing* also describes ancient sages as acquiring ideas for inventing and creating artifacts through their examination of natural phenomena and the relationships between humans and nature. Another passage from the *Kaogong ji* explains this point further:

> Heaven undergoes seasonal and climate change, the land exhibits geographical differences, materials have various properties, and artisans possess different types of creativity and skill. Gathering these four can produce good products. (Wen 1993, p. 5)

Here the *Kaogong ji* offers an interesting Chinese comparison with Aristotle's four causes: material, formal, final, and efficient. Chinese view the artificial world by way of the natural world, of which human beings are also regarded as a part. The Chinese view can be exemplified through a description of making of an ancient carriage, "The square of the cross board at the rear of a carriage is the symbol of the earth, the round of hood is heaven, the thirty-arm of wheel is the thirty days of each month, and the twenty-eight- bow-hood frame is twenty-eight constellations" (Wen 1993, p. 53).

Whereas Aristotle projects his four causes, which are derived from reflection on human activity, into the natural world, the *Kaogong ji* limits itself to aspects of the world that the human worker needs to consider, with no analysis of reality as a whole or metaphysical speculation, reflecting a distinctive "this-worldly" commitment. *Diversarum schedula artium* also includes some comments on the making of artifacts, but due to the influence of Christianity, its observations tend toward the theological.

> [T]he artist must work in humility, inspired by the holy spirit, for without this inspiration he could not attempt his work. Anything that he can invent or learn or understand about art is the fruit of the seven gifts of the holy spirit. Through wisdom he understands that art comes to him from God; through understanding he comes to know the rules of variety and measure; through counsel he is willing to pass the secrets of his craft on to his pupils; through fortitude he achieves perseverance in his creative struggles; and so on for the rest of the seven gifts. (Eco 2002, pp. 100–101)

6.4 Confucianism: Ethics over Technics

Confucianism has dominated all Chinese thought since its inception during the Spring and Autumn Period (771–476 BCE) when it was established by Kongzi [Master Kong or Confucius] (551–479 BCE), who is considered chronologically the first teacher in China and one of the most influential thinkers. Confucianism aimed to be an "ethical-sociopolitical teaching" (Nosco 1998, p. 550), though it later developed metaphysical and cosmological elements in the Han Dynasty (206 BCE–220 CE). In its ethical-sociopolitical origins, responding to a historical situation of disorder and warfare, Kongzi argued for revitalization through a return to an authentic practicing of the *Zhouli* [Rites of Zhou], a collection of traditional laws, regulations, ceremony, and customs shaped in the Zhou dynasty (1076–441 BCE).

Critics often allege that Confucianism stressed morality over the development of science (and technics), not leaving room for science to grow independently and flourish (Li 2005, p. 408). However, the Confucian emphasis on individual human beings does not exclude “things”, since people cannot be separated from the community or society, nor the society from the whole of nature.

Confucius regarded the making of things as being secondary to but serving the needs of the ethical-political enterprise, and that learning and understanding about “things” can give insight into human affairs. For example, when Confucius explained the importance of the correct environment for individual self-cultivation, he used the principle of craftwork as an analogy:

> Zigong asked about benevolence. The Master said, “Any artisan who wishes to do his job well must first sharpen his tools. In the same way, when living in a given state, one must serve those ministers who are worthy and befriend those scholar-officials who are benevolent. (*Analects* 15.10, Slingerland trans. 2003, p. 178)

Favorable references to the technics of agriculture, astronomy, mathematics, and medicine can also be found in Confucian works. One well-known instance occurs in the *Kaogong ji* when it focuses on various types of craftsmanship. In addition, some philosophical concepts, formerly used in the discussions of scientific topics during this time, such as *yin-yang*, the 五行 *wuxing* (five phases), and 气 *qi* (life energy), were discussed at large by subsequent Confucian scholars. A good summary is provided by Shen Kuo (1031–1095), a Chinese polymath and statesman of the Song Dynasty (960–1279), in a remarkable document on early science and technology called the *Mengxi bitan* [Brush Talks from Dream Book] (1088). In Shen’s eyes there is no contradiction between Confucianism and science and technics (Li 2005, p. 408).

Although Confucianism focused on human beings more than nature the humans it was most concerned with were the *junzi* [gentlemen] rather than ordinary people, since it was believed that these two types of person have different social roles based on different characters. The former, when he understands rightness, is capable of being the exemplar of ritually correct behavior and the ruler of society; the latter, who only understands profit, is able to be skillful with specific practical arts and needs to be ruled.

> The Master said, “The gentleman devotes his thoughts to attaining the *dao*, not to obtaining food. In the pursuit of agriculture, there is the possibility of starvation; in the pursuit of learning, there is the possibility of salary. The gentleman is concerned about the *dao* and not about poverty”. (*Analects* 15.32; Slingerland trans. 2003, p. 187)

The idea of a social division of labor also is held by another Confucian scholar, Mengzi, the most influential classical Chinese philosopher after Kongzi. According to him, “Those who labor with their minds govern others; those who labor with their strength are governed by others” (*Mengzi*, Book 3 “Teng wen gong”, part I, chapter 4; Legge trans. 1895, pp. 249–250). For this reason, it is not surprising to find a story of Confucius criticizing his disciple Fan Chi for learning about plowing and growing grain (*Analects* 13.4) and Mengzi rejecting the idea that sage kings should plough with the farmers, as put forward by Xu Xing (*Mengzi*, 3 “Teng wen gong”, part I, chapter 4).

In general, classic Confucianism always took the ethical-political enterprise as the highest priority, and considered other human activities, including technical ones, as secondary. While not opposed to technics, and even recognizing the importance of the role of technics in society, Kongzi did not encourage his followers to become involved with it (Chen 1988, p. 286).

6.5 Daoism: Technics as Intuition and Distraction

Daoism is also an important ancient Chinese tradition that includes both philosophical as well as religious components. Daoist philosophy (*daojia*, literally "*dao* family or school"; sometimes *daoxue* or "*dao* learning") and Daoist religion (*daojiao*, literally "*dao* teachings") have each contributed greatly to a proto-Chinese philosophy of technology, though with different starting points and trajectories of development.

Classical Daoist philosophy is rooted in Laozi (fifth century BCE), who is believed to have been an elder contemporary of Kongzi, and his follower Zhuangzi (369–286 BCE). As presented in Laozi's classic text, the *Daode jing*, Daoist philosophy held a different view than Confucianism about the cause of social disorder. It attributed the disorder to, in Laozi's words, the loss of *dao*, which is the universal principle, rather than, as Confucius believed, by a gap between what is socially desirable and its realization.

Laozi thought people lose connection with the *dao* when they have too many desires and too much knowledge, which causes them to act with artificiality and arbitrariness in attempting to satisfy their desires, the opposite of the naturalness and spontaneity of the *dao* (Feng 2007, pp. 160–162). While knowledge helps people satisfy their desires, it also generates more desires. For this reason, Laozi criticized science and technics, believing they were the cause of social disturbances and moral decay. For example,

> The unwrought material, when divided and distributed, forms vessels. The sage, when employed, becomes the head of all the officers (of government); and in his greatest regulations he employs no violent measures. (*Daode jing* 28; Legge trans. 1891, p. 18)

Here, 器 *qi* is the human created thing that lost its 朴 *pu* (simplicity), a key property of *dao*. This imperfection damages not only the thing itself, but also other things, its users, and society as a whole. Laozi thus wanted to limit technics and encouraged people to return to primitive ways of living.

As a follower of Laozi, Zhuangzi continued this tradition but contributed new content. One of the most fundamental differences between the two is their views of the *dao*. Zhuangzi agreed that the *dao* is the supreme principle of the world, but he converted it from the ontological principle to a value to be carried out in the real life in order to reveal its superb nature (Chen 1999, pp. 77–78). In his view, *dao* could be everywhere, but as the supreme principle, it should also be immaterial, invisible, and ineffable.

Zhuangzi thought the real world manifestation of *dao* was an artisan's extraordinary skills, which can also be sensed but not expressed in words, much like the *dao*.

The *Zhuangzi* (or Zhuang's writings) contains fables describing artisans who demonstrate great artistry, such as butchers, boatmen, wheelwrights, stonemasons, and arrow makers. A story about Butcher Ding cutting up an ox is well-known. Zhuangzi used Butcher Ding's explanation to King Hui about how to cut up a bullock skillfully to reveal the simplicity of the *dao*. According to Zhuangzi, Butcher Ding replied to a question from King Hui as follows:

> I have always devoted myself to *dao*. It is better than skill. When I first began to cut up bullocks, I saw before me simply whole bullocks. After three years' practice, I saw no more whole animals. And now I work with my mind and not with my eye. When my senses bid me stop, but my mind urges me on, I fall back upon eternal principles. I follow such openings or cavities as there may be, according to the natural constitution of the animal. I do not attempt to cut through joints: still less through large bones. (*Zhuangzi,* chapter 3 "Yang sheng zhu" [Nourishment of the soul]; Giles trans. 1889, pp. 34–35)

Butcher Ding attributed his exceptional skill to the *dao*, but here the *dao* also means a kind of knowledge that is difficult to transfer to another person orally or in writing. It depends on what might be called tacit knowledge. Zhuangzi's paean to the ancient artisans and their artistry relates to his and other Daoist's mystical doctrine of defending intuition over rationality. Zhuangzi realized the important value and role of intuitively acquired skill in early technics.

In seventeenth century Europe, Denis Diderot and his colleagues would create a great *Encyclopedie* of arts and crafts, contributing to development of the distinctly modern concept of technology. But these arts and crafts so carefully collected and described were never thought of as based in any fundamental insight into the nature of an invisible or profound reality. By contrast, Zhuangzi repeatedly present technical skill as growing out of and manifesting a unity of purposiveness, individuality, crafts-dominant, intuition, and inspiration (Liu 1995, p. 36).

Moreover, Zhuangzi realized that it was a long, hard process to understand and master tacit knowledge, even unconsciously. However, once artisans have done this, not only will they save time and strength, but the mundane and unpleasant work, such as cutting up an ox, may become artful.

> Prince Hui's cook [butcher] was cutting up a bullock. Every blow of his hand, every heave of his shoulders, every tread of his foot, every thrust of his knee, every swhshh [the sound] of rent flesh, very chhk [the sound] of the chopper, was in perfect harmony—rhythmic like the dance of the Mulberry Grove [an ancient music], simultaneous like the chords of the *Jingshou* [the name of an ancient movement]. (*Zhuangzi,* chapter 3 "Yang sheng zhu" [Nourishment of the soul]; Giles trans. 1889, p. 33)

The artisan's superb skill was highly commended by Zhuangzi, but he had a different view of the results of an artisan's work, that is, the world of artifacts. The artificial world easily distracts those who live within it from the reality of the *dao*. One famous example is a fable about watering the garden with an shadoof in the chapter of *Tian di* [Heaven and earth] chapter of the *Zhuangzi*. Human activity changes the nature of the original materials used to create the artifact, causing them to lose their original nature or the *dao* in the process.

Given the negative judgment of products, why no objection on the artisan's skill, which is the cause of the artificial things? In Zhuangzi's eyes, artistry is a natural instrument for human purposes. Whether it will become good or evil in a social sense depends on keeping it within its proper bounds (Liu 1995, p. 38). Zhuangzi criticized artisans for making so many artificial things that they obscured the *dao*, even though he very much praised their superb skill in the actual making. In his words, "destruction of the natural integrity of things, in order to produce articles of various kinds—this is the fault of the artisan" (*Zhuangzi,* chapter 9 "Ma Ti" [Horse Hoofs]; Giles trans. 1889, p. 108).

Daojiao or Daoism as a religion arose during the Eastern Han dynasty (25–220 CE). Like *Daojia* it considered the *Daodejing* a supreme classic and the *dao* as the supreme reality but then deified Laozi as the embodiment of *dao* and the founder of *Daojiao*. Because of the principle of trying to be immortal through making pills of immortality and cultivating vital energy, the Daoists experimented in various fields, such as chemistry, mineralogy, biology, botany, pharmacy, medicine, anatomy, sexology, physics, mathematics, astronomy, cosmology, and so on. The principle held by *Daojiao* "was of incalculable importance to science" (even technology), and "stimulated the development of the techniques of alchemy almost certainly earlier in China than anywhere else" (Needham 1956, p. 139), though the experimentation lacked systematic rational thinking.

6.6 天工开物 Tiangong kaiwu: A Seventeenth Century Chinese Encyclopedia of Technics

The sixteenth and seventeenth centuries were a period of great change for both China and the world. During the late feudal period in China, capitalism began to emerge and contribute to developing a commodity economy, which greatly improved the progress of science and technology, as well as society. It also generated works such as the *Tiangong kaiwu* that describe these changes, including changes to techniques.

The *Tiangong kaiwu* is an integrated work on agriculture and handicrafts published in 1637; it was written by Song Yingxing (1587–1666), a Chinese scientist during the late Ming Dynasty (1368–1644). As E-tu Zen Sun and Shiou-chuan Sun observe in their English translation, his *Tiangong kaiwu* "covers practically all the major industrial techniques of its time, from agriculture, textiles, mining, metallurgy, and chemical engineering, to the building of boats and the manufacture of weapons" (Song 1966, p. vii), including almost 30 different fields of agriculture and handicrafts production in China. During the same period, other works such as the *Nong zheng quan shu* [Complete treatise on agriculture] by Xu Guangqi published in 1639 and the *Bencao gangmu* [Compendium of *materia medica*] by Li Shizhen published in 1596 focused only on individual topics such as agriculture or pharmacy. The *Tiangong kaiwu* became the leading source in the country at that time of information about technics because of its wide range of content.

Song Yingxing's personal experience of failing the imperial examination six times during 15 years helped him become aware of the ignorance and dishonor of the educated upper class who had no understanding of where food comes from or how clothes are made, but instead immersed themselves in so called knowledge like the *Sishu* [four ancient Confucian texts] and the *Wujing* [five ancient Chinese classics]. Accordingly, *Tiangong kaiwu* is neither a guidebook for artisans, nor a work aimed at seeking scholarly honor and official rank. Rather, as the translators observe, it is "a factual book on the arts and techniques that went into the making of the necessities of daily life, in an attempt to persuade the vast majority of the scholar-officials that these too were matters that merited attention" (Song 1966, p. viii).

In order to eliminate myth and superstition from his book and gain accurate first-hand knowledge, Song traveled all over the country and visited artisans and workers who were actually producing things. His detailed and accurate descriptions on the production process along with 123 vivid illustrations demonstrates that he had been to actual production sites and observed the processes.

In structure, the 18 chapters of the book begin with a chapter on cereals and end with one on jewelry. Song prioritized cereals and grain as more important to the prosperity of a country than the luxuries of gold and jade. As he wrote, "The present book is divided into three parts, the order of their contents arranged in such a way as to indicate my desire to emphasize the importance of the agricultural products and the subordinate roles of metals and gems" (Song 1966, p. xiv).

The priority of food over gold and jade was also present in other ancient Chinese works, such as the agricultural texts *Qimin yaoshu* [Main techniques for welfare of people] written by the Northern Wei Dynasty official Jia Sixie between 533 and 544 BCE. Even now, Chinese philosophers often attach greater importance to the practicality of technology, especially technologies related to the Chinese economy and people's livelihood.

During this same time period in the West, *De re metallica* [On the nature of metals] by Georgius Agricola, published in 1556, was a work on technics, but it focused on mining at the exclusion of agriculture and other practices. Song, by contrast, was more comprehensive, so that some sinologists have compared him to the famous French encyclopedists of the eighteenth century. Joseph Needham, for instance, called Song the "Chinese Diderot" (1969, p. 102). Even earlier, as Pan Jixing notes in a contemporary Chinese edition of the *Tiangong kaiwu*, the French sinologist Antoine Bazin (1799–1863) referred to Song's book as an "encyclopedia of technology" while Japanese sinologists and historians described it as "the counterpart of Diderot's encyclopedia" (Song 1992, p. 27).

The idea of *tiangong kaiwu* presents a uniquely Chinese approach to technology. Originally, the term 天工 *tiangong* meant "work by heaven" or "work of nature" from the *Shujing* [Book of Documents], and 开物 *kaiwu* meant "human knowledge of natural principles" from the *Yijing*. But Song Yingxing gave this combination new meaning. According to the explanation of Japanese historian of science Saigusa Hiroto, *Tiangong* refers to human creativity which goes beyond nature, while *kaiwu* refers to humans transforming according to their living interests things originally contained in nature (Song 1992, p. 17).

In Song's view, nature is rich in inexhaustible and precious resources, but these re- sources cannot be attained without human skills. Compared with the *Kaogong ji*, which focused on the four elements of climate, geography, material, and humans to produce good products, the *Tiangong kaiwu* emphasizes human skills over everything else. According to Song,

> Stored in the seeds of grasses and tree there is oil which, however, does not flow by itself, but needs the aid of the forces of water and fire and the pressure of wooden and stone [utensils] before it comes pouring out in liquid form. [Obtaining the hidden oil] is an ingenuity of man that is impossible to measure. (Song 1966, p. 215)

For Song, it is important to keep the harmony between nature and humans and in interactions between human activities (manual labor) and natural ones (natural powers). If this harmony is maintained, the crafts and skills of humans will even exceed the power of nature.

This book also anticipates to some extent the scientific spirit of the Enlightenment, paying much more attention to practice and experimentation than to theory and argumentation. Song criticized books and authors who only provided theoretical knowledge without indicating the means for readers to test the ideas. He himself practiced this approach and tried out many of the techniques described in his book, noting when he did not get the intended result.

> The above is a brief summary [of the well-known oils]. I have not touched on other kinds, of which the properties have not yet been completely tested, or have only been tried out locally and are not generally known. (Song 1966, p. 217)

The European Enlightenment took a similar approach, providing detailed quantitative descriptions of technical practices, such as the consumption of materials and energy, rates of production, the structure and measurement of devices, and even operating numbers. This kind of description is obviously akin to the research reports that are typical produced by modern scientists. The *Tiangong kaiwu* in many respects transcends medieval methods and incorporates mathematics in ways that points toward subsequence developments in modern science and technology (Song 1992, p. 19).

6.7 Conclusion

Briefly summarizing from the above analysis, it is possible to identify three key ideas as central in influencing Chinese ways of thinking about technics, and eventually technology. First, there is the absence of a Creator god (or, more positively, the sense of the material world as self-subsisting). There is nothing like the almighty or supreme God or Allah, as is found in Western thought, who creates the whole world, including humans out of nothing. On the contrary, in Chinese thought, although creation and destruction go on in the world (in cyclical patterns), the world as a whole cannot be itself created; the sages, or rather, humans create all things according to the universal principles.

Second, in China there has been an emphasis on practice (and the primacy of practical or political affairs in human life). On the one hand, this involves the promotion of "practical rationality" or "practical reason". As Li Zehou described it, "human rationality in ancient China … tended toward practical research that would help people obtain useful knowledge for their lives" (Li Zehou 1985, p. 303; Kim 2012, p. 282). On the other hand, the practical orientation in the Chinese context means the emphasis was not just on economic values such as high efficiency, increased profits, and reduced costs, but also on social goods such as familial bonding, shared prosperity, and a peaceful life for the people.

Finally, there is a concern for harmony between heaven and earth (that is, of human beings with the larger world in which they live). Humans and nature are considered as a whole, and the harmonious relationships between the parts (humans) and the whole (heaven or nature) is always the focus of thinking, specifically, attempting to achieve *tian ren he yi* [unity of heaven and humans].

These three features of Chinese culture—absence of supernatural creation, emphasis on practice, and the ideal of human-heaven harmony—provide the basis for a traditional Chinese philosophy that is distinct from the one found in the West. They continue to influence contemporary Chinese developments in the philosophy of technology and engineering, because in China there is not the strong break between traditional attitudes toward technics and modern attitudes toward technology and engineering that Carl Mitcham (1994), among others, has identified as characteristic of Europe and the West. The study of premodern Chinese attitudes toward technics is thus an important aspect of the philosophy of technology in China.

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Note on Translations Quoted English translations from the Chinese, as well as references to Chinese in English texts, have often been edited slightly to fit present uses.

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Chapter 7
From Engineering to the Philosophy of Engineering: Philosophical Reflections of an Engineer

YIN Ruiyu 殷瑞钰

Abstract Philosophy and engineering are two indispensable basic activities in modern society, with philosophy of engineering as a bridge connecting them. A "triism" of science, technology, and engineering is the foundation of the philosophy of engineering. Engineering thinking matters to engineers and is different from general theoretical thinking. It is the constructive, designing, and practice that reflects practical reason. Engineering should be aimed at public service, and the public should understand and take part in engineering. Engineering has a direct relationship on the public interest and social welfare. It by no means is and could become a field monopolized by experts.

7.1 Introduction

I've been working in the field of metallurgical engineering as an engineer for a long time. In the course of my engineering practice, my understanding of engineering widened and deepened step by step. Here I offer some personal reflections on the gap between engineering and philosophy, the nature of engineering, the role and responsibilities of engineers, the evolution of engineering, and the relationship between engineering and the philosophy of engineering.

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7.2 The Engineering-Philosophy Gap

The vast majority of engineers have thought of engineering and philosophy as two separate worlds without any communication bridges and intersections throughout their histories. It seemed to them that engineers and philosophers have almost nothing to do with each other. Engineers did not care about philosophy and philosophers did not care about engineering either. In the words of engineer Louis Bucciarelli,

> [P]hilosophy and engineering seem worlds apart…. [Because] engineers value little the problems philosophers address and the analyses they pursue … it would appear that engineers don't need philosophy. (Bucciarelli 2003, p. 1)

The situation is no better with philosophers. Philosopher Steven Goldman, for instance, criticizes philosophers for neglecting research on engineering practice. In Goldman's words, the "Western intellectual tradition displays a clear preference for understanding over doing, for contemplation over operation, for theory over experiment" (Goldman 1990, p. 127).

The situation in China is similar to that in the West. In a word, the prejudice against each other in the circle of engineers and in the circle of philosophers leads to a great gap between engineers and philosophers. However, this is a situation that can and should be changed. Indeed, in recent years some engineers and some philosophers both in the West and the East have changed their attitudes toward and opinions on the relationship between engineering and philosophy. On the one hand, some engineers have begun to reflect philosophically about their work. On the other, some philosophers have begun to regard engineering as an important object of philosophical study. This change is contributing to a bridging of the gap between engineering and philosophy and pointing toward the development of a philosophy of engineering.

During the last decade as an engineer, I have cooperated with Chinese philosophers to study philosophy of engineering and deepened my understanding of the nature of engineering and the essence of engineering activity. After graduating from the Institute of Iron and Steel Technology (now the University of Science and Technology in Beijing) in 1957, I began my engineering career as a technician in an iron and steel company in Hebei Province. During the next five decades, my career trajectory was from technician to engineer, from engineer to engineering manager, and finally to engineering strategy developer. In this trajectory my responsibilities shifted from the development of a specific technology to the comprehensive integration of technology with basic economic and social factors. As my experience enlarged, I gradually realized that science, technology, and engineering are different, but interlinked. Additionally, I gradually realized that engineering practice and engineering systems involve a variety of significant philosophical issues.

Of course, my recognition of the close relationship between engineering and philosophy came about slowly. It was a gradually deepening process that involved an ever expanding way of thinking as a result of changes in my engineering roles, organizational responsibilities, and research fields. I began to communicate and cooperate with Chinese philosophers, and now philosophical thinking has become more and more part of my engineering life.

Looking back on my engineering road to philosophy, I see how my engineering career has laid the basis for my understanding and my philosophical study of engineering. I have progressively realized that engineering has multiple connections with different aspects of science, technology, and society and is an activity that selects, integrates, and constructs various factors concerned with nature and society. As for me, philosophical problems are derived from engineering practice rather than from any simple deduction from abstract principles.

7.3 The Nature of Engineering

What is engineering? This question is answered in different ways by different people. My own view is that engineering is an independent activity, one that is not dependent on science or technology.

People often confuse science, technology, and engineering. One prevalent idea is that engineering is dependent on and an expansion of science and technology. But from the perspective of an engineer, engineering differs greatly from both science and technology. A decade ago, Li Bocong argued for a tripartite relationship among science, technology, and engineering that he termed "triism" instead of monism or dualism (2002). This is a view with which I agree. Science, technology, and engineering differ from each other in regard to elements, products, system formation, and social functions. For example, the products of scientific discovery are mainly scientific concepts and theories in scientific writings; the products of technology are inventions and technological patents; the products of engineering are primarily some forms of material wealth.

Focusing now on engineering, it can be seen to be a complex of social activities. Engineering involves many factors, which can be divided into two basic groups. One group is composed of technological factors: design, process control, construction, and various kinds of technological devices, machines, technological skills, technological methods, and so on. Another group is composed of non-technological factors, such as economic factors, social factors, political factors, ethical factors, and cultural factors.

Generally speaking, technological factors are more basic to engineering, but non- technological factors are also important. The two groups are interconnected; they interact and mutually promote each other. In society, the decision on an engineering project is often affected by non-technological factors, especially by economic factors. Sometimes, a political factor or a human factor may become the most important factor that determines an engineering project.

7.4 The Role and Responsibilities of Engineers

The aim of engineering practice is to produce various large-scale artifacts for human use. Examples include bridges and roads, new auto plants, and so on. In order to achieve the aim of engineering activity, engineers, investors, and managers must draw up a plan, conceive a design, construct and operate what has been designed. In fact, the entire process of engineering begins with design, passes through manufacture, implementation, marketing, and ends with the use of the results or perhaps the disposal of wastes. It is necessary for engineers to combine technological with non-technological factors in order to exert a positive or negative impact on nature, economy, and society. So we should study and understand engineering—along with the role and responsibilities of engineers—through relationships with nature, humans, and society.

From a philosophical point of view, it is humans themselves who reveal and reconstruct relationships between nature and society. It is through better understanding these relationships that we can better manage engineering. From the perspective of nature, engineering relies on and adapts to nature, and also properly transforms nature. Engineering is rooted in nature while reconstructing it. Engineering transforms the substance, energy, and information of nature into materials and products that humankind needs, thus changing nature into a humanized and artificial nature.

From the perspective of humans in general, engineering showcases the creativity, innovative capacity, and greatness of what it is to be human. Benjamin Franklin described the human being as a tool-making animal. From this perspective, engineering is the manifestation and further development of a basic aspect of what it is to be human. Clearly engineering activities grow out of one of the most important features of human beings.

From the perspective of society or human groupings, engineering is a direct productive force. Engineering activity transforms various resources into products or commodities, which produces market value (economic benefits) and social value (harmonious and sustainable development).

Engineering is thus at the center of these three relationships. The philosophy of engineering critically reflects on these relationships. The social function of engineering is different from that of science and of technology. Unlike science or technology, engineering is a direct and actual productive force.

7.5 The Evolution of Engineering

Engineering is a dynamic process with an evolutionary history. Absent an appreciation of its dynamic, evolutionary character, we will fail to understand and control engineering in its “living” character. We will see engineering only in a “dead” sense.

My personal experience of engineering practice in China testifies to the importance of its evolutionary character. One heavy responsibility of engineers is not just to manage contemporary engineering well, but also to be aware of the evolutionary trends that are manifest in it and to promote the right kinds of evolution. Because of the importance of evolution in engineering, after finishing our book on the philosophy of engineering (Yin et al. 2007), the Engineering Management Division of the Chinese Academy of Engineering took the lead in organizing scholars in the engineering and philosophical fields to undertake interdisciplinary research on issues concerning the theory of engineering evolution. A book on this topic was published in 2011 (Yin et al. 2011).

Studies on the theory of engineering evolution have some features in common with studies on the philosophy of engineering, and even more so on studies in the history of engineering. However, because it is focused on theory, it is not too involved in historical details. Our theoretical studies of engineering evolution nevertheless involve both theoretical work in the strict sense and case studies. Theoretical work touches on relationships among the theory of engineering evolution, philosophy of engineering, history of engineering, and analysis of basic concepts. Theoretically we need to distinguish between evolution in natural biological systems and evolution in artificial systems. Engineering evolution is intervened in by human beings, which makes the dynamics of engineering evolution more complex than in natural biological systems. Case studies can illustrate such theoretical distinctions in, for example, examinations of evolution in railway engineering, metallurgical engineering, China's Shenzhou spaceship project, information and communication engineering, petroleum engineering, chemical engineering and petrochemical engineering, and dam-based hydraulic engineering.

Case studies can also reveal various factors affecting engineering evolution. These factors can then theoretically be classified into four categories, according to their influence. The first category is thrust or propulsive force, which includes inventing new devices, inventing new technological methods, discovering new natural resources, investing capital, and so on. The second category is tension or the pulling force, which includes creating a new market, enlarging an original market, increasing demand for engineering products, discovering new uses for engineering products, and so on. The third category is the braking force, which mainly results from the limits of natural resources, energy supplies, land availability, and negative consequences. The fourth category is a screening or selecting force, which is expressed in selecting among different technologies that which is most suitable to realize some particular goal, setting engineering norms, and so on. Part of the role and responsibility of engineers is to pay particular attention to the complex relationships among these four factors through careful and concrete analysis of functions and consequences of different engineering projects.

Engineers must analyze and control the interactive relationships among these four factors in an interactive way rather than simply by some isolated factor or factors.

7.6 Engineering and the Philosophy of Engineering

Recognition of the need to consider the complex relationships between different factors in the evolution of engineering helps stimulate among engineers appreciation of the importance of philosophy. Another stimulus is recognition that engineering is a direct and actual productive force that deeply influences relationships between humans and nature, human happiness, and social progress. Along with the various factors in the evolution of engineering, engineers must take into account relationships between society and nature, human benefits, and progressive effects among different peoples. Finally, because engineering directly affects public interests and social welfare, the public has the right to understand and take part in engineering activities. Engineering by no means is or could become a field monopolized by experts. The fact that engineering activities must be understood and participated in by the public especially calls on engineers to realize the importance of philosophical thinking over technological thinking. Philosophical discussion of the value and importance of engineering is one of the best ways that engineers can communicate with the public.

Due to the importance of philosophical thinking, engineering educators must work to stimulate philosophical thinking of college students in engineering. The philosophy of engineering should be part of the process of cultivating engineers. Already in 1998, Carl Mitcham advocated the idea that engineers should philosophize (Mitcham 1998). In recent decades, the U.S. National Academy of Engineering and the Chinese Academy of Engineering have both devoted attention to the reform of higher engineering education. Many engineering educators, engineers, and scholars advocate cultivating new types of engineers. Without philosophical thinking, it would be impossible to cultivate the kind of new generation of engineers that is needed today. In a small number of universities in both the East and the West, philosophy in engineering or philosophy of technology is now included in the curriculum and is becoming an important way to cultivate a whole new generation of engineers.

7.7 Conclusion

From my experience as an engineer, I gradually came to realize that philosophy of engineering matters to engineers. Although historically many engineers neglected philosophy, a number of engineers have changed their attitudes. Although it has not been described in any detail here, something similar has taken place in the circle of philosophy. Consequently, some engineers and some philosophers now carry out active and advantageous cooperation, which advances the development of the philosophy of engineering. Combining theory and practice is central to advancing the philosophy of engineering. The study of philosophy of engineering provides a deeper understanding of the nature of engineering and the evolution of engineering.

Through philosophical thinking, engineers are aware of their role in the society. Engineers must cooperate with philosophers and transcend professionalism. Engineers should not only be constantly perfecting their skills, but more importantly, should make themselves responsible for promoting social progress and the harmony of humans with nature.

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Part II
Philosophy of Engineering: Practical Issues

Chapter 8
An Engineer's Approach to the Philosophy of Engineering

Erik W. ASLAKSEN

Abstract The view of a practicing engineer on how philosophy relates to engineering provides definitions of engineering, technology, and their connections. A practicing engineer also holds distinctive views about the boundary between engineering and society, which significantly influences many issues currently under discussion in the philosophy of engineering. Of additional relevance to philosophy of engineering is the design process and the transition from functional requirements to physical realization. Within design in the functional domain there exist a number of issues that also deserve philosophical analysis.

8.1 Introduction

This chapter presents the personal views of a practicing engineer about what is included in the philosophy of engineering and what some of the outcomes of applying philosophy to engineering might be. Philosophy as a discipline in its own right is the domain of philosophers, but the "philosophy of something" must necessarily relate to and involve the practitioners of the "something". The situation is analogous to that of, e.g., the "engineering of mining", which must involve the mining community and relate to the activity of mining, how it operates, and what its purpose is. The approach to the philosophy of engineering presented here arose as a result of taking a closer look at some of the processes and methodologies employed in engineering, especially in what is generally considered to be the core activity of engineering, that is, design. When we observe the design activity in engineering, it appears to lie somewhere in the middle of the triangle formed by art, science, and craft.

Design draws on science for its knowledge about nature and for its analytical procedures. It resembles art in its creativity. It has much in common with the crafts in its use of experience and heuristics. However, when going beyond these externally observable features and trying to understand design as a coherent activity

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based on a set of basic principles, one comes up against issues and questions that are also found in philosophy.

In order for it to become a subject of philosophical enquiry, engineering needs to be placed in an ontological framework. That is, we need to have an agreed upon understanding of what engineering is in order to talk about it and address our philosophical enquiries. There are a number of ontological frameworks or higher level ontologies, most of which, such as the Sowa Diamond (Sowa 2000) or the Ontological Sextet (Jansen 2008), include an entity identified as a *process*. In the present context, we shall define a *class* of processes (they could perhaps be called professional processes) by the following definition of a class member (Aslaksen 2011):

- It is performed by people (the *practitioners*)
- It has a *purpose* defined by a group of people (the *stakeholders*)
- It is performed within a *timeframe*, starting with the definition of the purpose and ending when either the purpose is deemed to have been achieved or the attempt to achieve it is abandoned.
- It has a *resource base*, from which the resources required to achieve the purpose are extracted.
- It has a *knowledge base*, from which the knowledge of how to apply the resources is extracted.

Many instances of processes do not fall within this classification, such as the change of seasons, erosion, and the processes taking place within stars. It equally includes a wide range of processes outside of engineering, for example, in medicine, dentistry, and architecture.

Engineering forms a sub-class of this class, distinguished in part by the nature and content of the resource base and the knowledge base, and by tradition (as is the delineation of any profession). The resource and knowledge bases of engineering constitute what I consider to be *technology*; this is in contrast to some authors, notably Li Bocong (2010), who consider technology to be an activity. The engineering disciplines, such as civil, chemical, electrical, and mechanical engineering, are distinguished by some subdivision of the resource and knowledge bases, and the practitioners of the process are the *engineers*.

8.2 Purpose of Engineering

A central issue in the philosophy of engineering is the purpose of engineering. It is also a central part of most current definitions of engineering. For example, the ABET definition contains the following description of its purpose: “to develop ways to utilize economically the materials and forces of nature for the benefit of mankind” (ABET). However, instead of focusing on the class of processes called “engineering”, another approach is to focus on instances of this class, used in the above definition of the class, called *projects*. In terms of engineering projects, it is possible to distinguish two broad types:

- Projects that utilize existing resource and knowledge bases to meet a *need e*xpressed by all or a part of society
- Projects that increase resource and knowledge bases.

Projects in the first group *apply* technology, in order to meet requirements imposed by entities or people who are generally not engineers, and it is these stakeholders that are the judges of project success. Projects in the second group *develop* technology, using that part of the knowledge base that is provided by science, and their success is judged generally by other engineers. Let us call these two groups of engineering projects *application projects* and *development projects*, respectively. There is not a sharp boundary between them, and there will be many projects that contain sub-projects of both types.

The importance of this distinction becomes apparent when we consider some of the characteristics of the work undertaken by engineers in the two project groups:

- The projects in the two groups differ in the *distance* from the work of the engineer to its effect on society, and thereby in the level of responsibility and accountability and, more generally, the ethical issues involved. In the case of a development project, such as the development of a new type of semiconductor device or a new type of fastener, the engineer has no control over what the work will eventually be used in; it could be a weapon of mass destruction or a lifesaving piece of medical equipment. In the case of an application project, the engineer normally has a good idea of what the work will be used for and its intended effect on society.
- While engineers in both types of projects will receive reward in the form of personal satisfaction, the more tangible aspects of the reward structure are considerably different. In a technology development environment, the reward is mainly peer recognition based on published results and in an elevation to more senior status in the development organization. In an application environment, the reward is more likely to be a gradual transition out of design (see below) and into project management, business development, and corporate management roles, with commensurate privileges and remuneration increases.
- The scope of the work that engineers undertake (or the roles that engineers play) within the two types of projects differs. In development projects, the work is mainly comprised of core engineering activities such as studies, experiments, design, and fabrication. In application projects, engineers may additionally be involved in project management, procurement, construction, commissioning, community consultation, and engagement with various stakeholders, such as debt providers.

However, despite these differences, projects within both groups have a purpose that is external to the engineer; without such a purpose it would not be engineering, but rather art (as self-fulfillment) or simply playing or dreaming. Different projects have different purposes, but if we reduce the level of detail in the description of the projects, they start to form groups with the same purpose. For example, both a motorway project and a rail project can be thought of as having the purpose of providing public transportation. And as we continue to decrease the level of detail in the description, we come to ask: Is there a purpose common to all projects?

I believe the answer is yes, and to justify this, we need to look more closely at the process of engineering and its core: design. Design as the core of engineering has been recognized by a number of authors, as cited in van der Poel (2010). However, first, a basic question to philosophers: Why are "the engineering criteria of effectiveness and efficiency" thought to be an impediment to making engineering a subject of philosophical enquiry, and "engineering pragmatism may become for philosophy conceptual shallowness" (Vermaas 2010)? In response, let me adapt the opening lines of Aristotle's *Nicomachean Ethics*:

> Every art and every inquiry, and similarly every action and pursuit, is thought to aim at some good. Will not the knowledge of it, then, have a great influence on our actions? Shall we not, like archers who have a mark to aim at, be more likely to hit upon what is right? If so, we must try, in outline at least, to determine what it is.

So the fact that the good of engineering is usefulness is not an impediment to studying what it is and what its characteristics are; on the contrary, the philosophical outcome of being more likely to hit upon what is right is in itself very useful.

8.3 Design and the Process of Engineering

The execution of an application project involves the process of engineering. Central to understanding this process is realizing that its function is to meet a *need* expressed by society, or a group within society, as a part of stakeholder requirements. Engineers attempt to meet such needs by creating objects that satisfy the relevant aspects of the stakeholder requirements and, when put into operation, provide *services* that meets the needs. The measure of a project's success is the judgement of the stakeholders that the service meets the need. This process is illustrated in the diagram in Fig. 8.1.

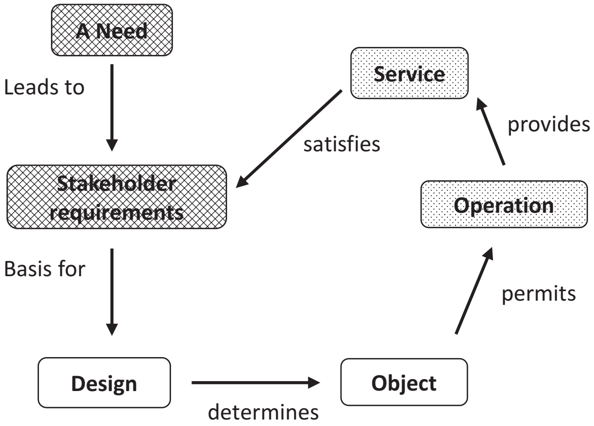

Fig. 8.1 The main concepts involved in the process of engineering

The shading of the boxes in Fig. 8.1 is intended to indicate that, while the process is called "the process of engineering", the degree to which engineers are involved in the different parts of the process varies greatly from project to project. Only the two solid white boxes, labeled design and object, can be unequivocally ascribed to engineering (a point returned to below).

Providing the service will have a *value* to that subset of stakeholders who expressed the need (often called "users"); thereby generating *revenue*. This value is not necessarily always measured directly in monetary terms; it may be through such outcomes as education, public health, social stability, military capability, etc. However, as the creation of the object to provide the service (often called the "system" or the "plant") will incur a *cost*, it is in the form of an *investment.* Again, cost may not always be directly in monetary terms; it could take the form of voluntary labor, degradation of the environment, depletion of non-renewable resources, etc. However, as Fig. 8.1 indicates, investments must be made before the object can start to provide a service. Decisions to make investments are based on some form of comparison between the costs and expected revenues provided by the users' valuation of the service, that is, on some projected *return on investment*. From this perspective, every engineering project is the pursuit of an investment opportunity.

Now, if the same revenue can be generated with a lesser investment or greater revenue with the same investment, or a combination of both, there would be every reason to choose this course of action. With this much generalized interpretation of cost and revenue, we can now formulate that the purpose of engineering common to every application project is *maximizing the return on investment*.

The significance of the existence of a common purpose arises from an approach to engineering called "systems engineering" (Blanchard and Fabrycky 2010), a methodology for handling the increasing complexity in engineering projects (Aslaksen 2006). The central feature of this methodology is to view the large number of requirements placed on a complex project as a set of interacting elements, where the interactions transform the set of elements into a system. And the process for developing the set of elements is a *top- down* process. Starting with the most general (least detailed) description of the project as a single element and developing it in step-wise fashion into larger and larger sets of elements, the individual elements arrive at a level of complexity that is convenient for us to handle. Having identified the common purpose of every project as maximizing a return on investment, the top-down process always starts from the common element that defines the return of investment. This introduces a structure into the space of functional elements and opens the way for developing reusable elements, and thereby greatly improves the efficiency of modeling and design in the functional domain (Aslaksen 1994).

Returning to the diagram in Fig. 8.1, it is important to be clear about exactly what is included in engineering when considering the philosophy of engineering. In what might be considered the narrowest interpretation, design starts with a set of stakeholder requirements. The professional obligation of the engineer is to design and build a system that, when put into operation, will produce a service that satisfies these requirements at the least possible cost, while observing all legal requirements, whether these are referred to in the stakeholder requirements or not. The professional obligation applies irrespectively of what the requirements are, and engineers should not let personal views and beliefs regarding the purpose of the project influence the quality of their work. This is similar to the medical profession, where physicians must provide the same care to sinners and saints, and to friends as well as to foes. In this interpretation, there needs to be a clear distinction between the engineer as a professional and the engineer as a member of society, and between engineering and the application of the results of engineering.

In a wider interpretation of engineering, we recognize that engineers may take on a number of different roles in projects besides design and construction, including management, operations, and sales. If these roles are included in engineering, then the interface between engineering and society becomes considerably wider and more direct, and the obligations of engineers now include ones related to the purpose and conduct of the project.

In the widest interpretation, engineering encompasses activities performed by engineers beyond projects, and may include a duty to inform public debates or influence the political process in matters where engineering knowledge and experience are relevant. It is evident that, as the interpretation is widened, philosophical aspects not only increase, but shift from mainly epistemological issues in the design process to ethical issues of the interaction with society. The scope of engineering is the subject of much debate, both in professional organizations and in the development of engineering education curriculae. What is important in the context of Philosophy and Engineering is to state clearly which view of engineering is being subjected to philosophical enquiry; to a newcomer to the field, there appears to be considerable confusion in this regard.

8.4 Philosophy and Functional Design

Squarely within the narrowest interpretation of engineering is my long-standing interest in the front end of design, or *design in the functional domain* (Aslaksen 2009). As projects increase in size and complexity, one can observe that when the outcome is less than satisfactory, the reason is more often than not in the formulation of the requirements rather than in any inadequacy of the engineering process itself. Somewhat simplified and idealized, the situation is that, as already mentioned, the stakeholders require a service, and they do not care how this service is provided. The power station or mobile telephones are examples of the engineers' solution to providing a service. However, instead of defining the service in solution-independent terms, it is easier and more convenient to define it in terms of an existing solution; that is, in terms of an existing physical object or process. It often does not take much analysis to see that a service or function is formulated with a particular solution framework in mind. We ask for a corkscrew when what we require is the function of removing the cork from a bottle. At the other end of the complexity scale, the ultimate functional requirement is for a good existence, an existence that fulfils our needs as humans (e.g., as identified and structured by Maslow), but our requirements are almost always formulated in terms of solutions we already have.

This is perhaps best illustrated in the use of military force and the tactics used to employ that force; the idiocy of marching forward in closed formation once firearms had been invented and of rushing infantry *en masse* against well-entrenched machine-gun positions are two examples, and one does not have to look far to see other solution frameworks being extended well beyond their use-by date.

Focusing on engineering, the first step in designing an object which, when put into operation, will meet stakeholder requirements for a service, i.e., the functional requirements in a set of stakeholder requirements, is to ask what the *functionality* of that object would have to be: what an object must *do* in order to meet the requirements. This is quite independent of what the object must *be*; in fact, there does not need to be any mention or involvement of a physical object at all. Functionality can be formulated independently of any particular object that will provide it; in a process of *abstraction* the service is represented by a point in the space of all possible functionalities – the *functional domain*. However, there will often be more than one way of providing a particular service, each one involving different functions and interactions between them, so that the service is represented by a set of points in the functional domain, and the choice of the most appropriate one is the purpose of an activity that might be called *architecting in the functional domain*.

Here it is relevant to note that the concept of function, as opposed to form or structure, has been the subject of a series of papers in the area of philosophy and engineering. In particular, by the research program in "The Dual Nature of Technical Artefacts" (TU Delft 2009) and also in a paper by Pieter Vermaas (2010). However, that program views function as one part of the description of an existing artifact, whereas the functional domain is not associated with individual artifacts at all. Functionality is prior to the existence of any artifact that provides the functionality (to a greater or lesser extent).

There will in general be a number of physical objects that can provide a required functionality, and so the second step in the design process, which is the *transition* from the functional domain into the physical domain, also involves a *choice*, as illustrated in Fig. 8.2. This figure indicates what often happens: taking a short-cut by going directly from the stakeholder requirements (i.e., the requirements on the service) to a physical artifact usually based on previous experience.

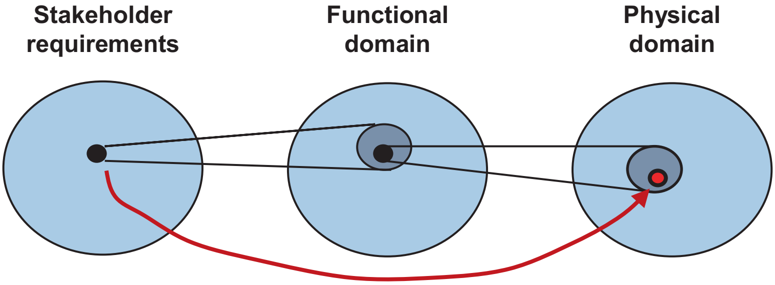

Fig. 8.2 The two-step design process, converting stakeholder requirements into a physical artefact that will meet those requirements

It is in this second step that the cause of much of what is considered to be the current inadequacies of engineering can be found, because as the functionality becomes more complex, not only is it increasingly difficult to ensure that one has identified all possible or relevant physical realizations, but how does one determine the decision criterion? What is the *best* choice?

One approach to handling that transition step in the design process is to apply the system concept: a mode of description that analyzes a complex entity as a set of less complex but interacting entities. Instead of formulating the functionality in terms of a particular, previously employed physical architecture and thereby attempting to make the transition from a complex set of stakeholder requirements directly into the physical domain (as illustrated in Fig. 8.2), we could first describe the functional stakeholder requirements as a set of smaller and simpler, but interacting, functional elements, and then make the transition into the physical domain for each element, while preserving the interactions. These *functional elements* define actions in the physical domain, such as "producing electric power", but without any reference to any physical entity carrying out the action. Developing and manipulating such functional elements is what I have called "design in the functional domain".

The functional domain raises a number of issues, many of which have a philosophical aspect:

(a) What sort of entity is a functional element? It is not a "thing"; it is abstract in the sense that one can never point and say "there it is", but one might point to something and say "there is a realization of it".
(b) What entities can be properties of a functional element? Obviously, "weight" cannot be one of them, but can we talk of the "size" or "complexity" of a functional element? Is the "size" one dimensional, or can we identify more than one dimension?
(c) What is meant by the interaction of functional elements? Is there a hierarchy of functional element, in the sense that one element can be represented by a set of "simpler", interacting elements? Are there "simplest" elements that cannot be represented by the interaction of other elements?
(d) Are there any sub-spaces of the functional domain? What is the topology, if any, of the functional domain? For example, can we talk of the "distance" between two elements? Is the functional domain a metric space?
(e) The study of the functional domain would seem to be closely connected to linguistics (Aslaksen 2012), but the relationship has not been explored in much detail.

These are just a few examples; I am certain philosophers can identify a number of other issues relating to the functional domain and its properties, and perhaps this paper can ignite some interest in this direction.

8.5 Conclusion

The upshot of my argument has been to offer for philosophical consideration a new understanding of functionality in engineering practice, one that is more attuned the real world of engineering work. At the same time, it notes some of the philosophical issues associated with engineering functionality that highlights epistemological, ontological, and ethical issues concerning the engineering-society interface. It is my hope that this short argument will stimulate more dialogue between engineering and philosophy.

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Chapter 9
A Biomimetic Approach to Complex Global Problems

James L. BARNES, Susan K. BARNES, and Michael J. DYRENFURTH

Abstract With scientific and technological advances giving rise to complex global problems, responding will require a different way of thinking than was involved in their creation. No longer are solutions bound within a domain of science or technology. Instead, solutions require a highly integrated approach across many domains, sciences, or technologies. What will become increasingly important is not engineering against nature as engineering with nature, as is emerging in the field of biomimetics. A discussion of sources and limits of knowledge that affect the biomimetic approach will provide an understanding for how mental models, metaphors, and analogies can be used to apply systems of nature with human systems to address complex global problems. Using this type of thinking can greatly enhance opportunities for solving, managing, or controlling the major complex global problems facing society.

9.1 Introduction

With the exponential factoring of knowledge due to scientific and technological advance, properly responding to complex global phenomena that become identified as problems will require a different way of thinking than that which originally gave rise to the phenomena. Because the phenomena at issue are no longer simply scientific or technological, a search for solutions requires a highly integrated approach across many domains, sciences, or technologies. Here we want to focus on designing sustainability solutions by integrating and applying knowledge of how organic systems (systems of nature) work with human systems; the nexus between deductive problem solving, trial and error reasoning, and inductive

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scientific inquiry; relationships between biological (cycles of nature) and technological (cycles of industry); and the ways science starts with a problem and is guided by theory while technology results in discoveries that lead to theories (Barnes 2011; McDonough and Braungart 2002).

Complex global phenomena come to be thought of as problems when they become counterproductive or otherwise fail adequately to meet the needs for which they were originally engineered. A problem-centric approach takes seriously the emergent character of such phenomena as problems and then responds by applying a systems understanding. Paramount to such an approach are questions concerning what knowledge is necessary and sufficient for understanding how organic systems work with human systems, how problem solving and scientific inquiry are properly utilized, and how the two metabolisms of biology and industry interact. A discussion of sources and limits of knowledge that affect this problem-centric approach will deal with how mental models, metaphors, and analogies are used to engage systems of nature and human systems in effectively responding to complex global problems.

9.2 Biomimetics

Traditionally, engineering has sought to design artifacts on the basis of its own principles (such as statics and thermodynamics) to meet human needs by creating increasingly complex global systems (of, e.g., transport and communication). The key to a new approach is biomimetics or biomimicry. While the discipline of biomimetics is an emerging field of study, in fact, humans have been using concepts of nature to solve complex problems for some time. For example, Leonardo da Vinci studied birds to gain an understanding of human flight. Biomimetics was originally defined by Otto Schmitt (1969) to describe the transfer of biological ideas to technology. The *Macmillan Dictionary* (2012) defines biomimetics as the study of systems and substances used in nature in order to find solutions to other human and technical problems. Janine Benyus (1997) defined biomimicry as a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems. In summary, biomimetics and biomimicry engineering involve the imitation of elements and models of nature to solve human problems that have arisen within previously engineered systems.

Here biomimetics focuses on how relationships between two metabolisms, biological (cycles of nature) and technical (cycles of industry), provide an understanding of systems of nature, how phenomena in nature exist, and how humans think those environments ought to be in order to design sustainability solutions by integrating and applying knowledge of how organic systems (systems of nature) work with human systems. This relationship opens doors to new technological solutions based on inspired biological engineering that includes nano- and macroscales. This type of thinking needs to be applied to complex global problems such as energy supply and demand, climate change biodiversity loss, energy poverty, water scarcity, food scarcity, waste storage, health, and critical infrastructure in order to seek fresh and sustainable solutions.

9.3 Basic Principles of Nature

Nature provides the largest laboratory ever created and the greatest knowledge base and opportunity for finding novel solutions to complex global problems. Nature itself has experimented with its own systems and cycles to refine the living organisms, processes, and materials. In nature, one by-product is the nutrient for another system. Nature's ecosystems can also transform nutrients from one form to another. Nature's energy source is primarily solar radiation. This energy is the same energy that powers all systems and cycles of nature, land, sea, and atmosphere. It is an efficient system, using only the energy it needs. Nature self-relates, with its systems and cycles cooperating with one another. In nature there is neither shortage nor scarcity; nature curbs excess. The relationships between the systems and cycles of nature depend on diversity. In nature, there is a cradle-to-cradle concept, where there is no waste; instead, waste is eliminated by the very concept of design (Gandhi 2010; Senge et al. 2008).

In contrast to the cradle-to-cradle philosophy, the industrial age philosophy was based on maximizing efficiency, a cradle-to-grave concept. Instead of zero-waste, the products of the industrial age are designed with built-in obsolescence, with 90 percent of the materials used to produce those goods becoming immediate waste (McDonough and Braungart 2002). Unlike systems and cycles of nature that produce more energy than they consume, the production of industrial age products uses more energy than is produced.

Based on this comparison, a biomimetic approach to complex global problems provides a novel way of answering the questions of what are the necessary types of knowledge and sufficient conditions to solve complex global problems, what are the sources of knowledge about nature that are most applicable, and how is such knowledge best structured or limited. Using this type of thinking can greatly enhance the opportunities to solve, manage, or control the major complex global problems facing society.

9.4 Problem Solving for Naturalistic Sustainability

Julian F. V. Vincent et al. (2006) suggest that there has not been any general framework or method for searching the biological literature for biomimetic functional analogies for technical functions. Most biomimetic solutions have focused on a single product, without application to complex global problems. For example, Qualcomm commercialized a display technology based on the reflective properties of certain morpho butterflies, using interferometric modulation to reflect light to control the desired color for pixilation display. The Swiss Federal Institute of Technology has incorporated the biomimetic characteristics of self-diagnosis and self-repair in their adaptive deployable tensegrity bridge design (Korkmaz et al. 2011). However, biomimetics provides not only analogies for single-focused products, but also provides many opportunities for building mental models for solving complex global problems.

Based on the work of William McDonough and Michael Braungart (2002), James Barnes developed a guiding definition for studying complex global problems through a biomimetic problem-centric approach. This definition focuses on "designing naturalistic sustainability solutions by integrating and applying knowledge of how organic systems (systems of nature) work with human systems, the nexus between problem solving (deductive reasoning) and scientific inquiry (inductive reasoning)" (Barnes 2011, p. 1). Furthermore, Barnes also identified six resources of sustainability: (1) networks or systems, (2) life cycles, (3) sustainability factors, (4) designing environments, (5) applications of nature, and (6) funding sources.

Networks and systems in the context of problem solving for naturalistic sustainability means bringing transdisciplinary stakeholders and experts together to solve complex global problems. They include those technical and human systems, with benefit from applying systems of nature to design sustainable solutions. Life cycles in nature refer to a cradle-to-cradle dynamic, wherein one by-product is the nutrient for another system, not a cradle-to-grave concept of waste. Nature's ecosystems can also transform nutrients from one form to another. In other words, life cycles never end and produce zero-waste.

Sustainability factors are those factors that promote a positive outcome for sustainable solutions. Such factors include social impacts, economic viability, capacity to deliver, community involvement, energy and carbon management, adaptability, and flexibility. In the context of problem solving, naturalistic sustainability applications can be described as how systems and cycles of nature are understood and applied through mental models and analogies to solve complex global problems. The designing environments factor addresses how to create naturalistic sustainable solutions that apply how humans think those environments ought to be to complex global problems. It involves integrating and applying knowledge of how organic systems (systems of nature) work with human and technical systems. The funding sources factor refers to the ability to secure the necessary funding to conduct the appropriate research, design, and implement naturalistic sustainable solutions with the ability for long-term stability.

In addition, Barnes (2011) identified six restraints on sustainability: (1) scarcity, (2) lack of understanding of nature, (3) lack of integration, (4) unwillingness to change, (5) waste, and (6) risk levels. In the context of solving for naturalistic sustainability relative to restraints on sustainability, scarcity is based on a simple principle which states "everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment" (Environmental Protection Agency 2012). Lack of integration refers to the stakeholders and experts inability to draw analogies and mental models of systems and cycles of nature and apply them to technical and humans systems. An unwillingness to change is a restraint that deals with a community's reluctance to accept a sustainable solution. This unwillingness to change could be because of social or cultural values or political instability or corruption. The waste restraint refers to the inability to move towards an acceptable level of waste or reach zero-waste for the naturalistic sustainable solution. Risk level restraint means that naturalistic sustainable solutions cannot be safe enough to implement or that the community will not accept the solution due to their pre-conceived perception of the risk level of the solution.

Supply and demand of resources must be factored into the equation for solving complex global problems. Thomas Friedman (2008) identified three key supply issues relative to solving complex global problems: (1) scale of demand, (2) scale of the investment needed to produce alternatives at scale, and (3) scale of time it takes to produce alternatives. The demand is based on the exponential factoring of population, seven billion today being projected to 9.3 billion by 2050.

In addition to these supply and demand issues, immediate impacts and long-term consequences must be factored in and controlled for as part of the design equation. New solutions create both positive and detrimental impacts, both immediate impacts and long-term consequences. The impacts and consequences can be social, cultural, environmental, political, and personal. For example, regardless of the intentions of stakeholders and experts brought to solve the complex global problem, they may be limited by the lack of understanding the application of how systems of nature can be used as analogies of technological and human systems to design solutions for complex global problems. As good as the knowledge and ability to solve complex problems by a transdisciplinary group of stakeholders and experts may be, not all the potential impacts and consequences can be known or controlled for. Sometimes the science or technology support the solution. The impacts and consequences may not be realized until decades later.

Central to naturalistic sustainable problem solving is an understanding of how relationships between two metabolisms, biological (cycles of nature) and technical (cycles of industry), provide an understanding of systems of nature, how phenomena in nature exist, and how humans think those environments ought to be. The concept deals with the integrative relationship of how science starts with a problem and is guided by theory, while technology results in discoveries which lead to theories. In engineering, scientific theories are applied to solving problems. In contrast, biomimetic thinking, as it relates to naturalistic sustainable problem solving of complex global problems, requires adapting systems or cycles of nature to technical and human systems (Vincent 2003; Vincent et al. 2006; Vincent and Mann 2002).

To solve problems by mimicking nature's systems requires not only a knowledge about nature's systems and cycles, but also a keen understanding of how systems and cycles of nature function, how to observe them, and how to apply them to technical systems that results is an optimum solution – one that is the best fit for a given environment. Using mental models, such as analogies, patterns, trends, tendencies, and mental simulations, provides excellent tools for understanding how systems and cycles of nature function and how they can be applied to solving complex global problems. Successfully solving complex global problems requires networking stakeholders and experts in a collaborative, transdisciplinary environment (Barnes 2011; Koutsouris 2010; Lenau and Mejborn 2011; Madni 2007).

9.5 Applications of Naturalistic Sustainable Solutions

In nature, one by-product is the nutrient for another system. Effectively applying this concept to solve complex global problems requires an understanding of how nature's systems function and how understanding those systems can be accomplished through building mental models, metaphors, and analogies. Global biogeochemical cycles, localized ecological recycling of organic and inorganic matter back into production of living matter, are regulated by food webs moving particulate matter from one generation to the next. The natural evolution of earth's ecological systems allows for solar energy to flow or mineral nutrients to sustain for billions of years.

Some examples of the application of naturalistic sustainable solutions can be found in emerging research. Studying leaves provides an understanding of how to balance out carbon dioxide levels in the atmosphere. Coral reefs are self-generating organisms that inform medical research. Nature's ecosystems transform nutrients from one form to another, a process that could provide a model for innovations in agriculture. An understanding of the hydrological cycle can be applied to design a water catchment system to solve water scarcity problems in an African village or a home off of the water grid. In both cases, rainwater is collected in a tank, dispensed to the villagers or residents for daily use, discharged into a sanitation system to produce grey water to raise crops in the field or in a greenhouse, and finally evaporated back into the atmosphere for the cycle to start over again.

Permaculture sites create symbiotic systems by integrating plants, animals, landscapes, structures and humans. Designing permaculture sites for sustainable farming builds on the basic principle of nature that diverse systems in nature can self-relate from its systems and cycles cooperating with one another. These sites are designed with back-up components that provide resiliency for the system to survive even if one component fails. A web of life is formed through multiple relationships within the system. Planting many species at once and letting natural evolution proceed provides a process of natural succession (Central Rocky Mountain Permaculture Institute 2012).

Designer Jeremy Faludi studied termite mounds and then used the ventilation system of that ecosystem to design a ventilation system for a building in Zimbabwe. The building does not need air conditioning, saving approximately 90% on energy costs (Hengst 2009).

9.6 Conclusion

Exploring the relationships between two metabolisms, the cycles of nature and the cycles of industry, opens the door for new opportunities for responding to complex global problems. Understanding systems of nature, how phenomena in nature exist and how humans think environments ought to be, will provide analogies and mental models to create innovative solutions to either solve complex global problems or at least to slow down the progression of those problems. The unlimited capabilities found in nature offer numerous possibilities for responding to human problems and needs. As the field of biomimetics and naturalistic sustainability evolves, so does a greater understanding of nature's capabilities and principles. Thus, transdisciplinary stakeholders and experts will be able to design naturalistic sustainability solutions to improve the quality of life for societies. This advance will allow scientist and engineers to either copy or develop inspired models of nature's systems.

Yoseph Bar-Cohen (2011) emphasized that the advance of biomimetics will require an understanding of how these inventions involve multiple science and engineering disciples across a wide range of scales. He recommends the importance of future biometicists to develop a capabilities of nature catalog in engineering terms, which could greatly benefit medical, military, consumer products, and other fields. Julian F.V. Vincent et al. (2006) recommend the systems approach known in Russian as Teorija Reshenija Izobretatel'skih Zadach (TRIZ or Theory of Inventive Problem Solving) as a transparent model for establishing a common set of principles for accessing biological systems. Similarly, the Biomimicry Innovation Method is a systems model used to identify biological systems, processes, and materials that can inspire novel solutions by emulating nature's patterns and strategies (Gebeshuber et al. 2009a, b). For example, the next generation nanoscale devices will likely require a combination of biology integrated with materials science and engineering. According to Rajesh Naik and Morley Stone (2005) future biomimetic research opportunities will focus on research that moves beyond description to more innovative approaches to biological integration and fabrication. Francois Barthelat (2007) emphasizes the importance of biomimetics as the key to characterizing hard biological materials, such as nacre and bone, to build the next generation of composites with enhanced strength and toughness. In the future, researchers who can think beyond boundaries will be able to more readily solve human problems and needs, such as space and ocean exploration, medical breakthroughs, and sustainable dwellings.

Naturalistic sustainability and biomimetics offer the promise of learning from nature's laboratory.

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Chapter 10
The Philosophy of Engineering and the Engineering Worldview

Terry BRISTOL

Abstract The philosophy of engineering is, in the first instance, concerned to make sense of what we do and how we do it as agents in the world. It is also concerned with understanding the nature of inquiry and exploration in the engineering enterprise. In these latter concerns, the philosophy of engineering constitutes the more general framework for understanding the nature of reality and the role of engineering in it. The philosophy of engineering and the engineering worldview supersede and subsume the philosophy of science and the scientific worldview.

10.1 Introduction

The philosophy of engineering is, in the first instance, concerned to make sense of what we do and how we do it as agents in the world. It is also concerned with understanding the nature of inquiry and exploration in the engineering enterprise. In these latter concerns the philosophy of engineering supersedes and subsumes the dominant twentieth century logico-mathematical philosophy of science.

The philosophy of engineering conceives of the engineer and the engineering enterprise quite broadly. Engineers understand themselves as problem solvers and ‘the problem’ to be solved is the problem of design. For instance: How should we design the irrigation of our fields? How should we design our houses? How should we design tools for these tasks? How should we design our neighborhoods and our cities? How should we design our economy? Tariffs or not? How should we design our political system – to preserve and defend our economy and our neighborhoods? How should we design our inquiries– the research and development activity of our society? The engineer, so conceived, is not merely a toolmaker or a creator of novel, useful artifacts. The engineer is equally a system designer, and a system developer.

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Another crucial aspect of the proper engineering self-conception is that the engineer has the ability to alter the scientifically expected course of events. Indeed, the engineer has the ability to alter the structure and operation of reality. In practice, of course, this ability is always limited by current capacities and competencies.

As a natural extension of the philosophy of engineering, the engineering worldview considers what the world must be like if the engineer is doing and is able to do what he actually thinks he is doing and able to do. The engineering worldview is a developing understanding of the place and role of the engineer and the engineering enterprise in the universe. Clearly the engineering worldview differs considerably from the scientific worldview – the latter being that of a mechanically deterministic eternal clockwork studied by means of the classic logico-mathematical philosophy of science of the last century.

The twentieth century philosophy of science was never self-referentially coherent. The philosophy of engineering is a broader, more comprehensive, self-referentially coherent view of ourselves (viz. as engineers) and our place in the universe. Capturing the more general context, the philosophy of engineering supersedes the limited perspective of the philosophy of science. Similarly the engineering worldview is able to understand and subsume the successes of mechanical theories, seeing them as limited special cases within the more general framework of the universal engineering enterprise.

The move to the correct, self-referentially coherent philosophy of engineering requires a paradigm shift, and as such can only be arrived at through a series of critical reflections on the limits of the philosophy of science. Similarly the correct, self-referentially coherent engineering worldview is found through critical reflections on the limits of the scientific worldview. The reason it has been so difficult to advance beyond the rather obvious inadequacies of the classical philosophy of science and scientific worldview is that there is no simple reasoning from within these existing paradigms that can lead to a conceptually revolutionary, more general, superseding paradigm. You cannot reason from the experience of the limits of science – in scientific terms – to the superseding engineering framework. Even though the later, more general conceptual framework, can understand the successes of the earlier – albeit in a conceptually new way – the paradigm shifts to the more general understanding is, nonetheless, conceptually discontinuous from these scientific points of view. The inadequacies of the dominant twentieth century Logical Positivist philosophy of science were pointed out by Sir Karl Popper (1935, 1963), Thomas Kuhn (1962), Paul Feyerabend (1975), and Imre Lakatos (1965) among others.

Engineers Samuel Florman (1987, 1994) and Walter Vincenti (1993) pushed from the other side insisting that engineering was not ‘merely’ applied science and could not be understood within the scientific framework. Henry Petroski (2010) has recently argued that all inquiry, even what has been thought of as pure scientific inquiry, can only be properly understood within the engineering framework.

American Pragmatist John Dewey (1929) usefully contrasts the philosophy of science and the philosophy of engineering as alternative representations of real inquiry, characterizing them correspondingly as the Spectator and the Participant representations.

10.2 The Spectator Representation of Inquiry

In the spectator representation, inquiry is intent on discovering the objective nature of reality. Advances converge to the final theory of everything, a complete and consistent correspondence where theory matches objective reality (Barrow 1991). This conception of the enterprise of inquiry entails, indeed requires, a certain conception of reality (viz. the scientific worldview). In order for such an inquiry to be successful and to converge to reality, the nature of reality must remain constant. If the nature of reality were changing, perhaps randomly, convergence would be impossible. The spectator representation tacitly assumes that the nature of reality, the order governing all the phenomena of the universe, is invariant over time. The spectator representation also entails that our activity as inquirers doesn't alter the nature of reality. If our activity as inquirers were to alter the nature of reality, then the possibility of convergence to a fixed, timeless objective reality would be lost.

10.3 The Participant Representation of Inquiry

The participant representation of inquiry, which I identify with philosophy of engineering, immediately accepts that the activity of inquiry alters the nature, structure and operation of reality. This worldview precludes any ultimate convergence to the spectator's hypothesized time-invariant, objective, inquirer-independent reality. Engineers naturally imagine they can and do alter the course of events. The participant-engineering representation entails that engineering research, development, and deployment progressively re-organizes the way the universe works. Articulating the consensus, Nobel Laureate Herbert Simon (1981) argues that engineering is problem solving and that problem solving is 'attempting to move from a current state of affairs to a more desirable future state of affairs'. Real problem-states are opportunity-states where alternative futures and alternative solutions are possible. The potential futures are embodied in the engineer and the situation. The engineering solution-state is conceptually different from the engineering problem-state. The conceptual difference is a qualitative difference – logico-mathematically discontinuous. A solution-state, as a more desirable future, is fully determined by the problem or opportunity-state. The Participant Universe – per hypothesis, the engineering universe – must have a qualitatively emergent (viz. problem solving) history.

10.4 From Philosophy of Science Toward Philosophy of Engineering

There were at least two separate lines of criticism in the philosophy of science that point toward philosophy of engineering (Ayer 1978). One is associated with Thomas Kuhn and the other with Karl Popper.

It is helpful to grasp that the Logical Positivist representation of scientific inquiry as logico-mathematical followed quite reasonably from one of the founding presuppositions at the beginning of modern science. Galileo, reaffirming the ancient Pythagorean thesis, argued that the language of nature was mathematics. The Positivists argued that mathematics was based on logic, so the order governing reality should be thought of as logico-mathematical. The subsequent dramatic successes of the Newtonian research program strongly supported the implicit scientific hypothesis: that all phenomena in the universe are governed by one universal logico-mathematical order. For the Positivists 'it stood to reason' that the successful method of inquiry (viz. scientific method) must be logico-mathematical. In other words, if the universe is governed by a logico- mathematical order, then the path to a complete comprehension of that order must be a logico-mathematical scientific method. The popularity of the logico-mathematical philosophy of science led many, including Stephen Hawking (1988), to suggest that scientific inquiry could be, and soon would be, turned over to logico-mathematically programmed mechanical computers.

Thomas Kuhn tried to make sense of the actual history of scientific inquiry according to these Logical Positivist expectations. According to the Positivist's conception of successful inquiry, there should have been conceptual continuity. The relation between earlier and more advanced scientific theories should have been logico-mathematical.

Kuhn came to argue against the Positivist conception, maintaining that the evidence of the history of science forced him to conclude that, literally, all the major advances in the history of science were logico-mathematically discontinuous, that is conceptually revolutionary. The earlier and later theories were incommensurable, meaning that later theories were not just extensions of the earlier theory. Feyerabend and Lakatos, in support of Kuhn, argued that if we actually learn something, then later understandings must be qualitatively and conceptually different from the earlier ones. Kuhn argued that even with considerable counter-evidence pointing to the inadequacies of an earlier theory, there was no way to logically reason to a more advanced theory.

In his relentless critique of the Logical Positivist representation of inquiry, Kuhn began to articulate the characteristics of actual inquiry. Most importantly, he saw inquiry as problem solving and as genuinely exploratory and experimental. Along the same lines, Feyerabend argued against the idea that there was one universal scientific method. This idea was equivalent to denying that there was one time-space invariant path to learning the solution to all possible problems.

The second major line of criticism of the Logical Positivist representation of inquiry is associated with Popper. The most recognizable theme associated with Popper is that all meaningful scientific theories must be falsifiable. Popper's concern had been to distinguish real science from pseudo-science. He noticed that what he took to be pseudo-scientific research programs had a habit of trying to explain away counter- evidence by giving after-the-experimental-failure accounts of why the failure didn't count against the theory. Explaining away typically appealed to extenuating circumstances or unexpected interfering factors. These after-the-fact responses came to be codified in the literature as auxiliary hypotheses. Frustrated by these endless defensive excuses, Popper reasoned that any legitimate (viz. truly scientific, self-critical) research program should be able to articulate prior to an experiment or, indeed, prior to any and all possible experiments, what evidence, if it were to occur, would lead the proponents to abandon the core hypothesis defining their research program. The demand can be called, Popper's Question: what evidence, if it were to occur, would lead you to abandon the core defining hypothesis of your research program (Popper 1963)?

However, it quickly became apparent that many legitimate scientists, rather than answering Popper's question, employed these defenses of their core hypotheses. Lakatos offered a thought experiment where a well-confirmed theory of planetary motion encounters unpredicted behavior of the outer planet. Does the legitimate scientist simply abandon the theory? Such an expectation came to be called naïve falsificationism. Rather, Lakatos suggests that his scientist offers an auxiliary hypothesis that there is another previously unknown planet in an outer orbit that is disturbing the known outer planet. The scientist calculates the expected position of the newly hypothesized unknown outer planet, and points a telescope to the position. When no planet is detected, the scientist then offers another auxiliary hypothesis that there is a dust cloud blocking the telescopic view and convinces NASA to send a space probe out to observe, avoiding the dust cloud. Several years later the results are in. Oops! The space probe didn't see any new planet. Still committed to the core hypothesis of his theory of planetary motion, the scientist reasons that there must be some sort of electro- magnetic interference with the space probe. Outer space is known to be a hostile environment. He proposes yet another space probe, and so on. The lessons of Lakatos's thought experiment are that scientists use auxiliary hypotheses quite regularly and that such use is considered quite legitimate – noting that any one of the auxiliary hypotheses might have been successful. Lakatos introduced the notion of a research program to capture how a series of improving theories, as in the planetary example, can be thought of as based on the same general core defining theory of planetary motion. Another lesson is that it is unclear just how long this rationalizing defense of a core hypothesis can reasonably continue. (For an illustrative case study of an ongoing research program, see my treatment of 'Dark Matter' (Bristol 2015).

Given that legitimate scientific inquiry frequently uses auxiliary hypotheses, Popper's insistence that all meaningful theories must be falsifiable takes us beyond naïve falsificationism, to a deeper understanding of Popper's Question. Legitimate, self-critical research programs, according to Popper, should be able to state and articulate what evidence, if it were to occur, would lead the proponents to abandon the core hypothesis. Any proponents should be able to specify – here and now, in this universe – how one would be able to falsify the core hypothesis. This prior specification and falsifiability is only possible if in fact the core hypothesis is *actually* false in this universe. The entailment is that all meaningful, falsifiable theories must *actually* be false. What is meant by 'false' here is simply 'incomplete', conceptually incomplete.

Even highly successful theories incorporate idealizations, and consequently, they are technically false in the sense of being conceptually incomplete. Unexpectedly, the incompleteness turns out to be demonstrated by evidence that, by its very nature, cannot be conceptually made sense of in terms of the conceptual apparatus of the original core hypothesis.

What I refer to as the surprising answer to Popper's Question' is that you can't articulate the falsifying evidence from *within*, or in terms of, the conceptual apparatus of the core hypothesis in question. What Popper's Question is asking for is a *type* of evidence that cannot possibly be made sense of in terms of the research program defining the core hypothesis.

The surprising answer to Popper's Question means that for every meaningful, falsifiable theory there must be some conceptually discontinuous phenomenon in *this* universe. That same falsifying phenomenon can then presumably be understood as confirming an equally meaningful, falsifiable complementary theory.

The Kuhnian and Popperian lines of argument both point to the inadequacy of the spectator representation of inquiry and learning. The arguments and historical evidence for the limits of this classical, Logical Positivist philosophy of science call for a more general, superseding representation of inquiry. However, as Kuhn's historical studies demonstrate, a theory plus counter-evidence to that theory does not automatically produce a superseding theory. The advance from one theory to a superseding theory is non-linear. The later theory is conceptually discontinuous with the earlier. One meta- lesson is that one can experience the limits of a research program while remaining in that research program.

As a student working with Popper, Feyerabend, and Lakatos, it gradually dawned on me that they weren't arguing *from* a theoretical position. Rather, through their increasingly penetrating and sophisticated critiques, they were backing into and toward an emerging new, more definite understanding. The meta-lesson is that new superseding paradigms only emerge gradually through a gradual, recursive and cumulative critical process.

The critique of the Positivist representation of inquiry led us gradually toward a More General Theory within which all meaningful falsifiable theories are understood to be naturally, conceptually incomplete. All successful theories are limited special cases, idealizing selections of limited aspects of reality. The More General Theory must be able to make sense of all possible purportedly scientific theories – but in a new way.

Both Kuhnian and Popperian critiques supply us with clues to a post-scientific, More General Theory. Kuhn establishes that learning is non-linear and involves conceptual revolutions. Our conceptual understanding of reality develops qualitatively. Kuhn argues that since learning is not logical, learning is problematic. Advances in understanding are solutions that cannot be simply reasoned from the prior understanding.

Another way to capture the practical sense of Kuhn's conceptual discontinuities can be seen in the common experience of researchers when they make an advance. Although there is a sense of having converged on the solution, there is an equal and often more powerful sense that the advance has opened up new questions. Qualitatively new types of questions can be formulated in the more advanced, superseding theory that could not even have been formulated in the prior conceptual understanding. Kuhn's 'conceptual discontinuities' are here represented as a consequence of the fact that learning is conceptually emergent and expansive. This process sounds a lot like the way things work in engineering design.

There are several important clues to the nature of the post-scientific More General Theory. First, all meaningful theories, by their very nature, must be incomplete (viz. falsifiable). Any falsifiable theory must be unable to make sense of at least some type of demonstrable phenomena in this universe. There must be at least one complementary, meaningful, and falsifiable theory for every potentially successful theory. As Lakatos pointed out, the very process of formulating a scientific theory involves a bias through making a choice. The observer selects one way of experiencing reality, using one type of paradigmatic experimental setup, rather than others. Lakatos argued, therefore, that every theory has evidence against it even at the moment of theory formation.

In his later writings Popper argued that all learning was problem solving (Popper 2001), suggesting a progressive evolutionary epistemology. Since the process of learning is embodied as an irreducible aspect of reality, Popper seems to favor a participant representation of inquiry in a progressively emergent, evolving universe, a kind of research and development worldview that is characteristic of engineers and engineering.

10.5 From the Scientific Worldview Toward an Engineering Worldview

The arguments and evidence supporting the thesis that the engineering worldview constitutes a more general framework subsuming the traditional scientific worldview arose with the new physics at the beginning of the twentieth century. The realization that there couldn't be a common conceptual foundation for the highly successful Newtonian and Maxwellian research programs (Carroll 2010) forced the embrace of complementarity (Bohr 1934, 1987). The particle in the Newtonian framework is conceptually discontinuous with the wave of the Maxwellian framework.

Complementarity implies that the participant-inquirer is encountering a universe that is not governed by one universal, objective order that uniquely determines all subsequent states. Complementarity entails that the future is under-determined by the present. The emergence of the actual future requires a choice. Remaining within the classical framework, this is often represented enigmatically as the collapse of the Schrödinger wave-function. This choice collapses the options of the possibility space. The observer's active choice is to implement one type of experimental setup rather than others that are possible. That choice is, by its very nature, scientifically arbitrary. It has no objective mechanical determinant. These limiting characteristics of the classical scientific worldview illuminated in the new physics generated the search for a More General, superseding, post-scientific, post-objectivist representation of inquiry and parallel understanding of reality.

Critical reflection points out that the choice entailed by quantum complementarity is, by its very nature, scientifically problematic. The choice, literally, cannot be made sense of within the framework of the deterministic scientific hypothesis. However, in the framework of the philosophy of engineering, complementarity is embraced and the choice is naturally understood as the active embodied ability of the participant engineer acting in the world.

In the engineering worldview, the problematic character and associated uncertainty of the choice is not only retained, but also newly understood as the irreducible experimental and exploratory aspect of all engineering enterprises. It is this genuinely problematic and qualitative character of the choice that makes engineering solutions emergent.

The spectator to participant paradigm shift can be represented as a problem shift. In the scientific framework the detached spectator's problem of inquiry is to understand how the world works – objectively, independent of the inquirer – with no anticipation of practical benefit. In contrast, in the engineering framework the participant's engineering problem is how to work in the world – how to problem solve, how to move, practically and beneficially, from a current state of affairs to a more desirable future state of affairs. Where the scientific worldview struggles and can only represent the choice as arbitrary, the engineering worldview understands the decision as a free choice between possible futures. The freedom is an embodied enablement that can increase or decrease with circumstances, and can evolve with learning.

Many twentieth century proponents of the scientific worldview understood that their defining presuppositions entailed a reversible (viz. symmetrically reversing) steady state model of reality (Hoyle et al. 1993). However, contemporary cosmology now accepts the evidence of the Big Bang model as entailing a beginning and a historical emergence through a series of symmetry breaking events (Weinberg 1977). Subsequent symmetries and states of mechanical organization are unpredictable, logico- mathematically discontinuous, and under-determined by the prior order.

Whereas it is unclear whether the spectator representation and the scientific research program can ever make sense of the Big Bang and the series of emergent, spontaneous, and symmetry breaking events, the engineering worldview naturally expects evidence for a qualitatively emergent, conceptually discontinuous history of the cosmos.

10.6 Three Examples of the Paradigm Shift to an Engineering Worldview

Against the background of the argument so far, let me provide further examples of this shift from a scientific spectator worldview to an engineering participant worldview. One is from pragmatist philosophy, another is from biology and socioeconomics, and a third is from engineering itself.

10.6.1 Royce's Criterion of Self-Referential Coherence

American Pragmatist Josiah Royce argued for Dewey's proposed shift from the spectator to the participant perspective by pointing out that any self-referentially coherent understanding of the universe must be able to make sense of itself (Smith 1969). In other words, the knower and the theory itself must be included in the universe that is to be known. The theory must also be able to account for and make sense of how it was learned. For instance, there would need to be physicists in the physicist's universe that somehow learned the physicist's Theory of Everything. As with Kuhn and others, Royce takes learning to be inherently problematic, requiring real, embodied and novel exploration and experimentation. Since any acceptable theory and its having been learned must be part of the universe, Royce reasons that learning as a process must be an irreducible aspect of any self-referentially coherent understanding of reality. Correspondingly, any meaningfully knowable universe must have a learning process as an irreducible aspect.

The issue Royce addresses is not about self-referential consistency – where consistency might be thought of in logico-mathematical terms. The emphasis on coherence means that any acceptable theory must have the conceptual richness to be able to make sense of the problem of learning and the resulting conceptual developments. Just as there is no way to make sense of quantum choice in the scientific worldview, there is no way to make sense of real questions in any mechanically deterministic universe. Indeed, the quantum choice can be reasonably represented as a question. The contrast that Royce is pointing out is that there is no choice and there are no questions *inside* the mechanical scientific universe. There is no way to make sense of inquiry in a deterministic universe. The scientific spectator representation of inquiry, revealingly, places the inquirer and inquiry itself outside the objective universe.

Suggestive of an overall engineering worldview, Royce argues that since learning is a form of problem solving, any self-referentially coherent understanding of reality must have real problem solving – and embodied participant problem solvers – as irreducible aspects and components of reality.

Accepting Simon's simple definition of problem solving as the attempt to move from a current state of affairs to a more desirable future state of affairs, the engineering worldview naturally sees the universe as attempting to self-develop, evolving through a recursively enabling, cumulative problem solving process. Learning and problem solving are not the abstract spectator's convergence to a final understanding of a fixed reality. In the participant engineering worldview, learning and problem solving are embodied in the universe's emergent research, development, and deployment enterprise.

Like the pragmatists, engineer Walter Vincenti (1993) argues that engineering provides a more comprehensive epistemological perspective. Engineering is clearly not merely applied science. Rather, what has been represented as scientific knowledge is perhaps merely a tool within the larger context of the engineer's creative problem solving. Petroski (2009, 2012) has further emphasized that, if one wants to better the world, this is the experimental, exploratory, and creative problem solving agenda of engineering: Want to engineer real change? Don't ask a scientist.

10.6.2 *The Place of Engineering in Biological and Socio-economic Evolution*

There is a fundamental conceptual discontinuity in the understanding of the history of life on Earth between the classical scientific worldview, which is identified primarily with the neo-Darwinian approach, and that of the engineering worldview. The move from the neo-Darwinian model to the engineering model requires, per the hypothesis, the same shift from a spectator to a participant perspective.

Critiquing the neo-Darwinian model, Stephen Jay Gould (1989) pointed out that if mutation were random, then if we were to re-run the tape of the history of life, we would have no reason to expect the current outcome, or even anything close to it. Moreover, Gould emphasized that the hypothesized natural selection itself has no overall direction. Adaptation is nothing more than the local natural selection *de jour*. In effect, the forces of natural selection are just as random, Gould maintains, as the mutations.

When you cannot in principle predict the outcome of a historical sequence, then you cannot explain the actual outcome. The introduction of chance-governed 'mechanisms' by the neo-Darwinian theory was apparently the only way to try to make sense of a progressive sequence in a Newtonian-like clockwork model that didn't naturally allow for any progressive, mechanically discontinuous, qualitative change.

Contemporary neo-Darwinians have abandoned the original inquiry to understand evolution as 'progressive' (Carroll 2006). Their current position is that the structure and operation of the modern biosphere is the result of chance. The unexpected consequence is that the neo-Darwinian theory must maintain that the history of life was random. The actual qualitative diversity of life forms is mechanically unexpected; again chance-governed. Similarly, the overall operational structure of the current biosphere, not being clockwork-like, cannot be understood in classical scientific terms and so must be considered random and chance-governed. The neo-Darwinian position is that the history of life on Earth is to be understood as directionless change, with no classical mechanical, causally scientific explanation. It stretches credulity to try to maintain, in light of the fossil evidence, the there is no definable sense in which there is a net progression over the 3.7B year history of life that led to the current biosphere.

When asked for the parameter of progress in evolution, neo-Darwinians deny that there is one, claiming that evolution is merely change (Carroll 2006). This default answer is a consequence of the impossibility of giving any account of qualitative betterment (viz. progress) in terms of a time-invariant order governing reality.

If the evolution of life is a qualitatively emergent engineering enterprise, then the unpredictable revolutionary engineering advances would appear – from the classical scientific perspective – to be non-law governed, in other words, chance-governed. In the engineering perspective, the neo-Darwinian chance-governed mutations are understood as creative solutions, as unpredictable inventions, and as logically discontinuous engineering advances (Reid 2007).

The shift from a scientific to an engineering worldview can be made by recalling that Darwin modeled natural selection on the long history of the engineering strategy of animal breeding: on artificial selection (Darwin 1859). Darwin left open whether artificial selection was to be understood as controlled by natural selection from a sort of spectator perspective as controlled by natural selection. His later writings however would indicate that he took that position (Darwin 1872).

However, consider the opposite problem shift – that all section is artificial. Selection is choice and quantum theory tells us that choice is ubiquitous. Accordingly, the direction in time of any system is determined by participant choice. In the engineering worldview, that choice is understood as embodied in engineering problem solving. Biological evolution in the engineering worldview is a sort of recursive, cumulative, bootstrapping engineering enterprise.

The neo-Darwinian thesis that mutations are the result of errors in reproduction also stretches credulity. If my theory of planetary motion fails to predict positions properly, can I just adopt the auxiliary hypothesis that the planets governed by the laws of planetary motion sometimes make mistakes? James A. Shapiro (2011) at University of Chicago has made a strong, evidence-based case that the genetic mutations that arise in biological systems are definitely not random.

Also important in this regard is the work of Robert G.B. Reid. In his monumental *Biological Emergences: Evolution by Natural Experiment* (2007), Reid argues that variations are a deliberate – albeit experimental and exploratory – strategy in life's engineering enterprise. What life is seeking is greater 'adapt-ability', increasing the capacity to do things and to explore new opportunity spaces. The strategy of evolution is not to learn to adapt to a fixed niche, but to learn by, and in order to, progressively explore and develop greater capacity to survive and thrive in a wider, emergent range of opportunity-spaces. In support of Reid's line of thinking, recent research shows that life is not merely filling timeless, pre-existing niches. Rather, life is emergent, creating and filing novel, including qualitatively novel, non-equilibrium niches (Odling-Smee et al. 2003; Hazen 2012).

In the neo-Darwinian model, life was supposed to be seeking a non-progressive adaptive equilibrium. The question of the origin of life's beginning non-equilibrium state of ignorance and uncertainty is never addressed.

10.6.3 George Bugliarello's Engineering Biosoma

Neo-Darwinian thinking curiously, but quite naturally, sees modern engineering advances as thwarting natural selection, allowing the less fit to survive and thrive. For instance, the development of insulin therapy has allowed Type 1 diabetics to survive and reproduce (Cooper and Ainsberg 2010; Bliss 2007). Advances in cystic fibrosis therapy have extended the average lifespan of victims from 12 years in the 1920s to upwards of 46 years currently (Gawande 2007). By neo-Darwinian thinking, these medical advances allow individuals to survive and reproduce who would normally naturally perish prior to reproductive maturity. Historian of medicine Thomas McKeown (1962, 1980) argues that nearly all advances in health and longevity in the modern industrialized nations has been due to engineering advances. The preventive measures, such as cleaning up water supplies, have been particularly effective. Those with weaker immune systems who would otherwise have died of cholera, typhus and dysentery – through neo-Darwinian natural selection – lived to survive and reproduce. These engineering advances are counter-evidence to the neo-Darwinian model, in the strong sense of Popper's Question, since the neo-Darwinian conceptual framework has no way to make sense of such progress.

Indeed, the argument for the contributions of engineering to what neo-Darwinians see as counter-evolutionary changes can be taken much further. Early agricultural advances, from irrigation and plowing to the domestication of animals, are engineering advances. Refrigeration and food preservation greatly expanded the availability of food. Without these engineering advances, natural selection would otherwise have greatly constrained population growth. The control of fire and the development of tools have also aided the survival of the weaker. The modern industrial revolution was based on engineering advances such as the development of the steam engine and the electric motor.

Rather than seeing engineering as unnatural and counter evolutionary, master engineer George Bugliarello (2003) has argued that modern engineering is a coherent extension of biological evolution. In Bugliarello's engineering view, the history of life is better understood as an emergent engineering enterprise. Bugliarello and colleagues also argue that engineering is a social enterprise (Sladovic 1991). In Bugliarello's biosoma (biology-society-machine) theory, biological evolution is the result of a self-enabling, experimentally bootstrapping, developmental learning process that results in new more powerful and qualitatively diverse ways to perform work in the world – new ways to do things, problem solve, and bring about a more desirable future.

An alternative history of life on Earth, supportive of the engineering view, also comes from an ecological approach to understanding the history of life. Ecologists study the successive historical relationships and the current operational relationships between diverse form of life and between ecological subsystems. The neo-Darwinian perspective, not seeing the expected clockwork biosphere, is unable to make sense of these relationships, consequently seeing them as chance-governed. Ecologists Dorion Sagan and Eric Schneider (2005) argue that the biosphere is a metabolic engine and that the history of life on Earth is a progressive development of that engine. Certainly there is more life and more types of life in the history of the biosphere. However, there is another factor that ecologists observe in the interrelationships between the various forms of life, in the structure, organizational design and operation of the biosphere as a whole. Sagan and Schneider argue that the biosphere as an engine has become better and better at performing work. Using an engineering imagery, the biosphere engine uses the energy gradient between the

Sun (hot source) and outer space (cold sink). The biosphere has emerged in a nonlinear manner, over its history evolving an increasing capacity to perform work. In the engineering sense of the concept of work, the biosphere has progressively gained an increasing capacity to do things, become more powerful, and developed more qualitatively diverse ways of living. In the engineering sense it has developed, concomitantly, an increasing capacity to explore and experiment. It has developed an increasing capacity to learn new emergent ways of doing things. It has developed an increasing capacity to bring about a more desirable future.

Economist Paul Romer picks up George Bugliarello's theme of the strategic continuity of engineering in biological evolution and modern human socio-economic engineering.

David Warsh (2006) tells the story of Paul Romer's paradigm shift in economic thinking. In classical scientific economics, the system always tends toward a non-progressive equilibrium. Any apparent progress was explained away by auxiliary hypotheses, attributed to external, exogenous (non-economic) causal factors. From a classical economic perspective, since economic law did not govern these exogenous factors, they were arbitrary and incoherent in terms of those laws, and so considered chance- governed.

By the late twentieth century, there was overwhelming evidence of dramatic increases in economic production and productivity over the last 150 years. These increases could not be made sense of in the classical, mechanical zero sum framework. Romer (1990) made the revolutionary shift in his famous 1990 paper "Endogenous Technological Change" by arguing that the economy is an engineering enterprise. He maintained that progressive technological development – finding and instantiating new better ways of doing things – was the defining characteristic of all functioning economies. This progressive development is what economic systems have always been doing and are always trying to do (Romer 1994).

Romer argues that a normally functioning economy (viz. metabolic system) is learning and actually generating and expanding its opportunity space. In stark contrast to the neo-Malthusian thinking of the Club of Rome's limits to growth (Meadows et al. 1994), Romer has been characterized as the post-scarcity economist. He argues that ideas (viz. engineering recipes) and new ways of doing things are the key to progressive economic growth and expansion. It is not a matter of how much land, water, iron, or gold that you have: It is about what you do with it, about what you do to bring about a more desirable future.

Neither populations nor ecosystems can increase and diversify without increasing opportunities, without *generating* net abundance. Without increasing resources and increasing capacity to perform work, the expansive history of life, noted by Sagan and Schneider, could not have happened. The observed historical expansion in quantity, qualitative diversity, organizational efficiency, and operational power of life is precisely what the Malthusian presupposition would not expect and cannot possibly understand. What has evolved is an embodied system that has expanded and continues to seek to expand its capacity to do things, to problem solve, to bring new value into the universe, and to bring about a more desirable future.

10.7 Conclusion

In his book, *What Technology Wants* (2010), Kevin Kelly explores the engineering worldview, making the case that the evolutionary path of progressive technological development is the 'unfolding of freedom' where increasing freedom is increasing ability to perform work and to do things in the world. A better title for Kelly's book might have been, *What Engineering Wants*.

The post-scarcity approach is part of the emerging engineering worldview. Matt Ridley, in his book *The Rational Optimist* (2010), and Peter Diamantis, in his book *Abundance* (2012), detail the acceleration of socio-economic-biospheric opportunity of the global engineering enterprise. William McDonough and Michael Braungart's *The Upcycle: Beyond Sustainability – Designing for Abundance* (2013) is another excellent attempt to articulate the overall vision of the abundance framework.

In contrast to the presuppositions of the deterministic scientific worldview, the engineering worldview understands the engineering enterprise (and itself) as creatively developing the future and constructively evolving both the organizational structure and operation of reality. The shift is captured by the problem shift from the spectator to the participant representations of inquiry. For the detached spectator, inquiry seeks to understand how an inquirer-independent (objective) world works. For the embodied participant, inquiry is part of the overall, emergent, bootstrapping engineering research, development, and deployment enterprise. The participant is seeking to understand better ways of working in the world and doing things in order to bring about, to instantiate, a more desirable future.

One further step in developing the philosophy of engineering and the engineering worldview would be the cosmology. Engineering cosmology has been competitive with scientific cosmology at least since Plato's *Timaeus* (Jowett 1959) argued that the universe has come to be as it is through the work of the *Architekton*, master architect- engineer (Zeyl 2014). All 'participants' in the universe are parts or aspects of this universal engineering mind. What I refer to as Sadi Carnot's Epiphany is that we are engineers in a world of engineering (Carnot 2005; Bristol 2015). We are participants in a universal engineering enterprise with abundant opportunity to continually develop the structures and processes of reality to bring forth a better, more desirable future. Carnot's Epiphany derives in part from his insight that all processes are less than 100% efficient, less that classically mechanical. This insight is in direct conflict with the calculus of variations and the principle of least action, which are maxims at the heart of the scientific hypothesis. A crucial next move in the articulation of the engineering worldview involves showing that engineering thermodynamics is more general and supersedes the limited, highly idealized attempt to understand thermodynamics mechanically in the tradition of Boltzmann (Bristol forthcoming).

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Chapter 11
Toward a Practical Philosophy of Engineering: Dealing with Complex Problems from the Sustainability Discourse

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Abstract This article characterizes the current philosophical approach to engineering and professional limitations in coming to terms with highly complex, socio-economic-technological problems, such as those that emerge from the sustainability discourse. It compares the philosophy of science which has for more than 70 years been vigorously involved with science. The result proposes a set of philosophical principles to enable the engineering profession to engage with the sustainability discourse. While some see engineering as an essentially values-free discipline, whereby science is harnessed for the common good, this paradigm has become outdated and engineers need to come to terms with the belief, values, and moral standing that characterize many of the problems facing twenty-first-century society. We need a "Copernican revolution" in engineering practice. In order to engage adequately with highly complex problems, engineers must see themselves as a part of the problem and the environment in which the problem exists, not as separate from it.

11.1 Introduction

It has been asserted that philosophy is the intermediary between theology and science and that all definite knowledge sits within the realm of science, while dogma belongs firmly in the domain of theology (Russell 1946, pp. 13–14.). Philosophy

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occupies the "no-man's land" between the two, between definite knowledge and dogma. Engineering is a practical discipline that, in order to be successful and avoid catastrophe, must rely on knowledge, not opinion. A practical philosophical framework for engineering will reduce the space occupied by this no-man's land, allowing engineers to engage with increasingly challenging and complex issues with greater confidence. In other words, establishing a sound, practical, philosophical framework for the practice of engineering reduces the influence of dogma and opinion and increases certainty of outcome.

Although engineering is often considered to be a technological science by non-engineers, there is an important distinction to recognize between science and engineering. Science is the systematic development of knowledge gained through experiment and study. The aim is to "know" so that we are freed from the need to rely on dogma and insufficiently justified belief. Engineering is less concerned with the philosophical question of whether science represents a true description of reality. Rather, it relies heavily on the presumption that science provides a practical instrument with which to model the observable world and to predict and control its behavior. Thus engineering is by its nature instrumentalist in that it seeks to use science to achieve an outcome that historically has been to serve the needs and desires of humanity.

Newberry (2007) refers to the approach of many engineers as one of "proximate instrumentalism", noting that most engineers are not particularly reflective in the social sense about the practice of their discipline. Some have seen engineering as an essentially "value-free" discipline, where science is harnessed in a way that can be used for the common good. This approach enabled engineering to be practiced with greatsuccess over the last century or so; however, the emergence of the highly complex problems of the sustainability discourse have changed the requirements of the profession, thereby challenging this conception of it.

These problems have been characterized as being of three fundamental types (Hector et al. 2009). Type 1 problems are those that normally yield to reductionist or systems-analysis problem-solving approaches, where relatively simple, objective decision-making techniques, such as mathematical modelling, computer simulation and traditional scientific and engineering methods, can be applied. Type 2 problems are those that, due to their complexity and the systems nature of the issue, require accommodation of reductionist, analytical, and both hard- and soft-systems approaches. Type 3 problems are those that, due to their uniqueness and complexity, preclude or limit the use of the purely analytical techniques. Type 3 problems also require engagement with stakeholders who have conflicting worldviews, irreconcilable beliefs and values, and a willingness to exploit power imbalances in a coercive way to achieve their own ends. The ethics of stakeholders may be difficult to identify and some, for example, non-human species, may not be formally represented in the decision-making constituency. It is the Type 3 problem that is of most interest here. This type of problem, due to its uniqueness and complexity, precludes or limits the use of the purely analytical techniques. Hence, the prevailing engineering paradigm has become outdated and engineers must consider critically the philosophical underpinnings of the profession so as to be able to come to terms with matters of belief, values, and moral standing that characterize many problems facing 21st-century society. If engineering is to maintain its relevance as a profession or, more desirably, is to re-establish the leadership it had in the nineteenth and early twentieth centuries, it must embrace this new problem typology and consider the philosophical and intellectual challenges in coming to terms with it. We do not advocate for a return to the engineering practices of a previous era, but rather to learn from the past and to create a new engineering paradigm for the complex problems of the sustainability discourse.

11.2 Characterizing the Philosophy of Engineering

One characteristic of an instrumentalist discipline such as engineering is that once a paradigm is established that can provide broadly acceptable solutions to a wide range of practical problems, there is no particular reason for the paradigm to change. The positivist approach to science developed a body of scientific knowledge around mathematics, physics, chemistry, electrical phenomena, and so on that formed a strong foundation on which much engineering practice is still based. Much of the fundamental science that provided the basis for modern engineering emerged in the first 30 years of the twentieth century at a time when the prevailing scientific paradigm was predominantly positivist, culminating in the Vienna Circle's logical positivism. Since the 1930s, the philosophy of science discourse has been strongly influenced by criticism of this positivist position.

Although positivism has been criticized extensively (see below), much engineering has developed around the positivist philosophical position. Thus, it is important to understand the strengths and limitations of this approach and current engineering practices in relation to the challenge presented by Type 3 problems. Much engineering design work is founded on experimentation and the construction of mathematical models that accept prevailing scientific theories as being true. It does not explicitly question the fundamental scientific validity of the models or the underlying realist ontological framework upon which the models are based. Although these models are recognized as abstractions of reality, there is no explicit engagement with the values and beliefs that influence model selection and construction. Often, there is no critical engagement in the underlying values assumptions upon which the models are based.

Engineering is inherently inductive, involving observation of the behavior of existing systems and carefully extending designs beyond the experimental domain. Just as the positivist approach was typically mechanistic and certainly atomist in nature, so too engineering relies on the reductionist approach. It construes the behavior of larger wholes as the sum of their parts, or at least as being some function of their simpler behaviors. Even in systems engineering, emphasis tends to be on the reduction of complex systems to workable subsystems so as to make system control methodologies practical.

At first glance, this approach appears to be not only sensible, but perhaps the only way that engineering can be practiced. There must be clear, rational, scientific principles underlying engineering design for the desired outcome to be achieved, provided these principles result in a practical solution to the problem and the limitations of the principles and simplified assumptions are understood. However, the Type 3 problem, with its values-laden character and its immense complexity that often defies holistic modelling, presents a significant challenge to the traditional, positivist engineering approach, still based largely on the Padua method. Other difficulties emerge from using this paradigm with Type 3 problems. Often assumptions made inductively outside the problem boundaries are found to be wrong. For example, engineering catastrophes are often the consequence of inductive reasoning turning out to be invalid. Additionally, there may be widely conflicting scientific theories under development to explain certain aspects of the problem. Furthermore, models constructed on these theories may produce divergent results. Social and political influences may overwhelm the technological issues and the traditional anthropocentric engineering solution may not be acceptable in a broader ethical context. The reductionist approach by its very nature tends to discard those things that are, or appear to be, incommensurate with the commonly accepted means of defining the problem. Hence, issues around values, the influence of beliefs other than those that are scientifically based, and the aesthetic aspects of the problem are either discarded from the problem definition or marginalized.

Perhaps the most significant deficiency of the instrumentalist engineering philosophy is that it tends to be *non-critical*. Engineering practice struggles to include aspects of the problem that do not have some form of scientific basis and because of this deficiency; it can overlook critical, non-technical influences on the problem. There is no established critical engineering approach to these factors other than various forms of stakeholder engagement and consultation that have evolved in the last 20 years, which rarely prove to be satisfactory. All of these issues are explored further to develop a set of philosophical principles for the practice of engineering that aims to provide a foundation for the framing of the highly complex Type 3 problem, so that the content of the problem is identified within the broad social and moral context in which the problem itself exists.

11.3 Science and Scientific Knowledge after Logical Positivism: The Post-Positivist Debate

Since the 1930s, the positivist position has come under attack from a number of quarters. There have been several important discourses around the philosophy of science. Philosophers, anthropologists, sociologists, and scientists have brought very different perspectives to the forum in considering the development of modern science. The first of these came from Karl Popper, who disagreed sharply with the logical positivist approach that reached its height with the Vienna Circle. Popper placed emphasis on Descartes' hypothetical-deductive approach in which notions such as causality were suppositions made not as inductively created hypotheses, but as assumptions that enabled a specific line of experimentation. Their purpose and justification was to create ever more powerful theories that would allow us to develop knowledge purely from our ability to reason and without reference to experience (Popper 1940).

Popper's views on the philosophy of science have been referred to as critical rationalism or "critical realism". He was not the first to attempt such an approach; R.W. Sellars (1924), Sterling Lamprecht (1922), Drake et al. (1921), and others had attempted a critical realist approach in early twentieth century America. But Karl Popper, with his theory of conjectures and refutations, advanced the argument substantially and stimulated considerable thought on the subject. Thomas Kuhn (1970), while acknowledging much common ground with Popper, suggested that science progresses through a series of relatively rapidly occurring paradigm shifts that are not unlike Gestalt switches (Kuhn 1962, pp. 12–22.). During the long periods between paradigm shifts, "normal science" proceeds to investigate phenomena within the prevailing paradigm. As normal science progresses, outcomes of scientific research start to identify inconsistencies within the current paradigm and dissatisfaction builds to a point where a new theory is proposed, which establishes a new paradigm. Since the 1930s, philosophers of science (for example, Feyerabend 1975, pp. 55–76 and pp. 147–158; Lakatos 1974, 1978, pp. 47–50; Hacking 1981a, b; Putnam 1981) recognized the inability of the mechanistic model to deal with the fundamental uncertainty of the world, the effect of human cognitive limitations, and the influence of beliefs and values on human thought.

One of the conclusions from the discourse on the philosophy of science was that there can be no such thing as the positivist assumption of an observer who is truly independent and detached from the problem. Engineers, like all participants in the problem space, bring their own individual beliefs and values to the situation. What is often overlooked is that values, politics, propaganda, and other issues are part of the fabric of human interaction and are woven into the scientific process and, therefore, implicitly into the practice of engineering. Thus, the importance of taking a critical position to the acquisition of scientific knowledge has been a key theme of this discourse. Two groups that have been particularly influential in the development of a critical approach are the Frankfurt School and the Edinburgh School (Brocklesby and Cummings 1996; Mingers 1980; Kincheloe and McLaren 1994; Niiniluoto 1999). Both emphasize the interrelationship between the observer and the observed, taking into account the sociological influences in the acquisition and interpretation of knowledge.

The Frankfurt School originated in the 1930s at much the same time that the Vienna Circle was at its height. Its proponents, Max Horkheimer, Theodor Adorno, and Herbert Marcuse, and later, Jürgen Habermas, developed critical theory, which followed an entirely different course than that of the positivists. Critical theory draws upon Hegelian idealism, the Marxist notion of a utopia resulting from natural consensus and unification of man, nature and history, elements of psychoanalysis (influenced by William James) and existentialism. It developed the proposition that the Enlightenment as it actually unfolded stalled the emancipation of mankind and its aim should be resurrected in order to emancipate, to level unequal power, to call upon mankind's fundamental goodness, and to use knowledge to eliminate inequality (Brocklesby and Cummings 1996; Mingers 1980; Kincheloe and McLaren 1994; Niiniluoto 1999; Ponterotto 2005). Critical theory placed an emphasis on the social nature of knowledge and, although it had a substantial influence on the discourse on philosophy of science, it does not appear to have had a particular impact on the practice of engineering.

This debate brought a critical dimension to the social sciences that had not been recognized by the logical positivists, yet preserved the logical positivist goal of construing the natural and social sciences as not being fundamentally different from one another. Cultural theorists such as Habermas, particularly in his theory of knowledge- constitutive interests and his theory of communicative action, have been influential in the approaches of the decision sciences. This influence is seen particularly in operational research and solving highly complex, "messy", social problems (for example, see Brocklesby and Cummings 1996; Mingers 1980; Ulrich 1983, 2003; Gregory 1996; Valero-Silva 1996; Jackson 1985). These problems might be thought of as the precursors to the Type 3 problem of the sustainability discourse and have been incorporated into a critical systems approach. This similarity suggests that a potentially fruitful avenue of investigation for the practice of engineering could be to develop a critical, less instrumentalist philosophy, that extends its systems approach beyond the purely technical into the arena of the social sciences in order to increase the relevance of engineering practice in the solution of Type 3 problems encountered in the sustainability discourse.

The Edinburgh School, which included thinkers such as Barry Barnes, Harry Collins, and David Bloor, approached the sociology of scientific knowledge (SSK) in an attempt to explain how scientific knowledge develops in a social context, rather than specifically defining a normative ontological and epistemological framework (Friedman 1998).

Bloor's "strong program" (Bloor 1973) was extensively criticized (for example, by Laudan 1981, 1982). However, in his more recent approach (Bloor 1996), he emphasizes that the important issue is that scientists use a set of organizing principles and rules for structuring their knowledge. Scientists' senses give rise to their perceptions of the world, but their inductive and deductive reasoning is built around culture. In other words, knowledge of reality is achieved through society, not despite it. The concept of the sociology of scientific knowledge has largely dispelled the notion of the independent, objective practitioner. The ontological foundation of SSK is both constructivist and relativist. This claim is rejected here because extended to its logical conclusion, it argues against external realism, which is the ontology that underlies engineering.

A more radical approach is the postmodernist view, expressed by Michel Foucault, Jean-Francois Lyotard, Jacques Derrida, and others, which questions the principles upon which all modernist rationality is based. Postmodernism is not a specific movement in itself; rather it is an aggregation of many views. However, there are two distinct streams of thought that can be identified: one that sees modernism as amoral because it holds us hostage to imbalances in power and another reactionary form that seeks to address the uncertainty of the human construct of modernity by returning to some utopian, authoritarian "golden age" (Jackson and Carter 1991). At least in decision science, postmodernist views have not been widely influential. (For relevant discussion of postmodernism in operational research, see Mingers 2000; Mingers and Brocklesby 1997; Flood and Romm 1996; Fishman 1995; Schwandt 1994; White and Taket 1994, 1996).

11.4 Toward a Practical Philosophy of Engineering

The first step in developing a practical philosophy of engineering is to propose an ontological framework. A useful ontology to consider is Popper's notion of Three Worlds. Popper argues that the dualist mind-body ontology of Descartes is not a sufficiently rich representation of the way the world is. He goes on to define a pluralist philosophy in terms of three "ontologically distinct sub-worlds" (Popper 1972, pp. 74–80 and pp. 153–161). The first World is that of physical states, the second is that of mental states, and the third is the World of objective thought. Popper distinguishes between two different senses regarding knowledge and thought. World Two knowledge is thought in the subjective sense. It comprises our states of mind, our consciousness, and our intentions. Popper refers to this as subjective knowledge, but a better term might be subjective knowings. World Three knowledge is knowledge without a knowing subject; it is knowledge that exists independent of the subjective mind or, in other words, it is the objective content of thought. World Two can interact with World One and World Three, but World Three can only interact with World One, by means of interpretation through World Two. Hence, one can view the mind as the means by which objects of World Three, such as thought, theory, argument, and so on are linked to the reality of World One. Thus objective knowledge can only be related to reality through subjective interpretation. According to Popper, one of the mistakes made by many philosophers has been to interpret objective thought as being subjective, that is, a part of World Two rather than World Three. Some things, for example language, belong to all three Worlds: the physical symbols of language belong to the first World; the subjective expression of ideas to the second World, while the objective aspects, such as theories and argument described by language belong to World Three. Even though the contents of World Three are a human creation, they exist before we become aware of them through our experiences in World Two. For example, prime numbers exist irrespective of whether or not they have been recognized in mathematics. It is not the intention here to offer a distinctly philosophical defense of Popper's position. Rather, it is accepted as a satisfactory ontological framework to enable critical examination of the issues identified earlier and to think about how we might structure our knowledge of the real world.

11.4.1 Engineering Practice Based on a Realist Ontology

The first principle proposed here is one of ontological realism; a physical world exists independent of the human mind. The only justification of this to be made here is framed around a common-sense argument. Consider, for example, the Taj Mahal. I have seen photographs and drawings of it, I have read rich descriptions of its architectural detail and beauty, and I have visited and walked through it. The experiences I sense when I visit the Taj Mahal are consistent with the images and mind-representations I have formed from photographs, paintings, and other representations that I have seen and from the vivid word-descriptions that I have read. The experience I have as I visit the Taj Mahal simply adds depth and richness to my mind-representation. When I see the Taj Mahal, the experience is much greater than when I close my eyes and imagine it, suggesting that there is more to the Taj Mahal than a simple mental representation. Commonsense suggests that it is absurd to propose that were I to cease to exist, so too would the Taj Mahal. As noted above, there are various forms of realism, some stronger than others, and these are well dealt with and justified by thinkers such as Popper (1972, pp. 34–44), Alan Chalmers (1988), Ilkka Niiniluoto (1999), Winston Churchill (1944, pp. 126–128), Susan Haack (1987), Hilary Putnam (1977), and John Searle (1995, pp. 149–176).

This position might be referred to as "naive realism", the notion that a physical world exists to which the human senses give us direct and immediate access. This would be true if the ontology could be applied to all three Worlds. However, the neo-Kantian argument that subjective knowings and objective knowledge of Worlds Two and Three are subject both to social influences and interpretation means that we must be critically realist about those things that belong to World Two and to World Three. In other words, the distinction is made between things that exist in the physical world and our subjective and objective representations of them. That is, we are naively realistic about things that exist in World One, but critically realistic about the contents of World Two and World Three.

11.4.2 Indeterminacy and Systems

The second contention is that the world is complex and that many of its physical and social characteristics are best represented by the notion of system. This proposition can be concisely stated in the following terms. Within the real world composed of what we understand to be matter, there appear to be arrangements of this matter that have emergent properties and relationships that cannot be described adequately using the reductionist approach. There appear to be systems in which the identifiable constituent parts interact in distinctive, irreducible ways, both with themselves and with other systems. In particular, some of these systems behave in ways that we characterize as having the properties of life. Some of these forms of life and living systems have the capacity to perceive and interact with their surroundings; that is to say, they are sentient. Furthermore, some of these sentient organisms have the capacity to think; they are cognizant. And beyond this, some are also sapient and are capable of self- conscious deliberation.

As far as we know, human beings have the most developed capacity for self-conscious deliberation. As a result, the formation of social systems is possible only for beings capable of such deliberation. The sapient nature of the human life form is an emergent, evolutionary feature, which imparts to our interactions with other beings the character of being evaluable in terms of being wise or unwise, good or bad, right or wrong, just or unjust, and so on. It is this sapience from which World Two knowings and, in particular, World Three objective knowledge emerge. A key point here is that the world does not simply consist of World One systems; where sentient, and in some cases cognizant life- forms are present, there emerge highly complex socio-physical systems with World One, World Two, and World Three constituents.

Engineering practice has been extraordinarily successful in its utilization of what has been largely a positivist, mechanistic view of the world, albeit recognizing and accepting that systems analysis is a powerful technique for predicting the response of and for control of complex systems. The practice of engineering has largely been confined to the physical world, or World One and World Three representations of it. But this paradigm is not sufficiently rich to engage in the Type 3 problems of sustainability and sustainable development. The point to be emphasized here is that a practical philosophy of engineering must recognize that indeterminacy and error are not merely due to model inaccuracy; rather, they are a fundamental characteristic of the way the world is. A challenge for the way in which these Type 3 problems are to be structured is to identify a way to represent problem information so that it makes clear the holistic, systemic nature of the problem across all its dimensions. Furthermore, the system paradigm presented here is not limited to World One phenomena, but rather extends to broader World Three and World Two influences. Hence, for engineering to be relevant and fully engaged in providing solutions to Type 3 problems, a practical engineering philosophy must be built on a broader view of the world that recognizes World One, World Two, and World Three interactions and influences, and encourages critical thought as the predominant means of identifying problems solutions.

One of the challenges in creating such a philosophical framework is that two quite different positions in relation to concepts of truth appear to be adopted by those who have traditionally followed the scientific approach compared to adherents of critical theory and social theory. It is important to have some understanding of these positions if a critical philosophical framework is to be developed. The next section will briefly describe these two positions, arguing that both approaches are valid, depending on the aspect of the problem being considered.

11.4.3 Thoughts on the Nature of Truth

At the heart of Type 3 problems is the need to reach some agreement on whether or not problem information or the discourse resulting from its consideration is true, and that it is an accurate representation of the problem situation. It is beyond the scope of this paper to enter into a lengthy discourse on truth; rather, the position adopted here simply will be stated and the rationale given as to why such a stance has been taken. In most considerations of truth, attention is given to two questions: what is the nature of truth, or what is meant by the term "truth" (or, more specifically, what is the meaning of the truth predicate, "is true") and what are the criteria for determining whether or not something is true? The focus here is confined largely to the second question.

Two influential theoretical approaches to truth that have been considered extensively in the twentieth century are the correspondence approach and the coherence approach. Both are substantive approaches that hold that such a thing as truth exists and that it is a property of, or a relation involving a "truth-bearer" (that is, a proposition, sentence, or belief-state) and a theoretical, omniscient "cognizer". Correspondence approaches propose that truth is correspondence with the way the world is and is independent from the cognizer, whereas coherence approaches argue that truth is coherence between truth-bearers and includes the relationship between the truth-bearer and the ideal cognizer (Schmitt 2004). Correspondence theories have their origins in Greek philosophy, whereas coherence theories are more recent, emerging in the late nineteenth and early twentieth centuries.

11.4.4 The Importance of Truth in Dealing with Type 3 Problems

The fundamental ontological basis of the critical, practical engineering philosophical principles being developed here is that there is a real world independent of the human mind. If we are to be able to relate to the real world, we need a means to accurately represent our theories, concepts, and models of real-world phenomena and to develop a means of communicating these representations with each other. Hence, a realist ontology requires a correspondence-based approach to truth. It is important to note that this conclusion is not based on the claim that acceptance of realism requires the commonly formulated correspondence theory of truth. Rather, the assertion made here is that if a real world independent of human thought exists, human thought needs a way to form accurate representations that in some way correspond to these independent real-world phenomena. Nor is it claimed that the correspondence theory of truth, as commonly formulated, is a satisfactory means of providing such a correspondence-based approach. Indeed, in a notable exchange between John L. Austin (1950) and Peter Strawson (1950), the generally accepted view is that Strawson largely dismissed the commonly articulated correspondence theory of truth as a means for understanding the meaning of truth, demonstrating that the argument was circular (Hamlyn 1962; Sainsbury 1998; Searle 1995, pp. 199–226). However, Strawson did not deal with the usefulness of the correspondence theory as a criterion for determining truth. Consideration will now be given to truth criteria that provide the means to interpret things and phenomena in all three Worlds.

11.4.5 Criteria for Truth: The Correspondence Theory

The correspondence theory of truth, as commonly formulated, is a linguistic approach and has been used to address both the question of the nature of truth, as the means to determine whether or not something is true, and as the criteria of truth. The commonly articulated correspondence theory is generally considered to be inadequate as an account of the nature of truth. However, if it is framed in linguistic terms, the concept of correspondence can provide the means for determining whether or not something is true (Hamlyn 1962; Searle 1995). Thus, the correspondence criterion of truth (that is, a correspondence theory for testing truth) provides an important means for linguistically testing our representations of objects and phenomena in the real world.

11.4.6 Coherence Approaches to Truth

The coherence theory has been influential in the decision sciences, particularly in social planning, and is becoming widely influential in the sustainability discourse. Of particular importance was the concept of coherence proposed by the British idealist, Francis Bradley (Davidson 1990). The argument put by Bradley (1909a, b) was that because of the fallibility of perception and memory, representations cannot be free of error and that conceptions of truth must be formed within the context of a systematic whole. More recently, coherence was further developed as a criterion of truth by Nicholas Rescher (1974). He contrasts the Euclidean model of the hierarchical acquiring of knowledge, based on axiom, theorem, and deduction, with a network model in which knowledge and theses are interconnected and such connections are determined not only by deduction, but also by inference. The important point here is that coherence approaches reflect the concepts of “wholeness” and “system”.

11.4.7 Using Both Correspondence and Coherence Criteria for Truth

Historically, the correspondence and coherence approaches are often placed in opposition to one another, with each taken to preclude the other. However, the two approaches are only in opposition when taken to be definitional, that is, as an explication of the meaning of the truth predicate. When considered specifically in the context of being criteria for truth, each can be assigned its place, depending upon the way in which the problem is defined and structured. Indeed, Popper (1972, pp. 308–318) notes that coherence approaches can provide valuable insight into problem situations, even though they cannot provide sufficient justification to determine truth.

In summary, the coherence approach in its criteriological sense is useful as a criterion of truth for beliefs, statements, or theories about things that are subjectively determined, such as norms, values, morals, ethics, aesthetics, and so on. But there are some beliefs, statements, and theories about things where the aim of inquiry is for them to be objectively determined, for example, mathematics, quantum mechanics, astrophysics, chemistry, and biology, and therefore should be considered correspondence- theoretically. And as noted above, the correspondence approach provides the means for determining whether or not our understanding of real world phenomena is true. (It is tempting to suggest that correspondence criteria should be used for World One and World Three phenomena and coherence criteria for World Two phenomena. However, this does not take into account that World One phenomena can only ever be interpreted subjectively through our World Two representations, and that certain World Three phenomena, such as theories of morality, ethics, and aesthetics, are determined largely through cultural norms that reflect collective subjective agreement.) Hence, in structuring the Type 3 problem, it is important to establish as much of the problem content as possible within an objective domain so that it can be tested using correspondence criteria, without compromising the need to utilize coherence criteria in relation to those things that are subjectively determined.

11.5 Principles for a Practical Philosophy of Engineering

The point has now been reached where a set of practical philosophical principles for engineering can be stated concisely. These are:

P1. There is a physical world that consists of mind-independent things.

P2. There is a mental or psychological world that is an emergent, human phenomenon with which the human mind represents its perceptions of the physical world.

P3. In a physical sense, there is an infinitely complex parade of events and phenomena located in space and time – this is "the way the world is".

P4. The world is fundamentally indeterministic in nature and its individual parts can only be understood in relation to the whole and in the context of the system.

P5. Although it is beyond the capacity of the human mind to understand completely and to describe adequately the way the world is, the human mind forms linguistic and other representations based on perception and thought that attempt to arrive at some "true" but incomplete understanding of it.

P6. Truth, a human phenomenon, may be considered from two perspectives. One is an objective "fact of the matter" that relates to physical phenomena and objective representations of the real world and these representations can be determined to be either true or false. The other is a subjective representation of socially determined phenomena and the truth or falsity of these representations is determined linguistically according to generally accepted and verified beliefs and values. In both cases, the appropriate position to take is to acknowledge them as being true or false, subject to the ever-present possibility of error and in the context in which their truth (or falsity) is determined. Both correspondence and coherence approaches to truth have their place but only as criteria for determining truth.

This framework draws heavily on the philosophy of Popper (1972, pp. 81–84) and Niiniluoto (1999, pp. 9–13), but also recognizes the social influences identified by Kuhn (1962), Paul Feyerabend (1975, pp. 20–24), and Imre Lakatos (1978). While it acknowledges some aspects of Putnam's (1977) concept of internal realism, it is more closely aligned with the notion of external realism by Searle (1995) and also, to some degree, the critical realism of Roy Bhaskar (1998), as criticized by Chalmers (1988). Of interest was the contrast between Popper and Habermas by John Mingers (2001), Mingers and Brocklesby (1997), and Gerald Midgley (1996) and, most particularly, the extensive analysis of the two theoretical approaches by Werner Ulrich (1983, pp. 27–34; pp. 175–177; pp. 81–85).

11.6 Practical Application of the Principles

In practical terms, how might the principles outlined in this paper be applied, particularly in the context of the Type 3 problem of the sustainability discourse? One way for these principles to be utilized is through problem definition and, in particular, problem-structuring. Problems ought to be structured in such a way as to recognize World One, World Two, and World Three aspects of the problem, but with acceptance that a purely reductionist approach is not appropriate with Type 3 problems. Type 3 problems should be considered as dynamic systems with World One, World Two, and World Three system components and subsystems. For those aspects of the problem that relate primarily to World One phenomena and their World Three representations (such as material things, physical events, physical processes, and the analysis and theories that describe them), a Popperian critical-rationalist approach, using truth criteria that are primarily correspondence-based is the most appropriate. For those aspects of the problem that have their origins in World Two and World Three phenomena and their World Three representations (such as beliefs, feelings, emotions, ethics, moral issues, and social phenomena), a Habermasian critical-theory approach, using truth criteria that are primarily coherence-based should be preferred. A purely reductionist approach to problem-solving is not a satisfactory means by which to come to terms with Type 3 problems, but because of the cognitive limitations that naturally prevent human understanding of Type 3 problems in their entirety, some reductionism is necessary to form a workable representation of the problem. It is important to recognize that such an approach can only ever yield an approximate representation of the system as a whole.

The crux of the argument presented here is that an instrumentalist philosophy of engineering practice is both dated and inappropriate for certain types of problem, in particular the Type 3 problem of the sustainability discourse (Hector et al. 2009). The notion of the detached, independent practitioner actually prevents the gaining of a holistic understanding of the Type 3 problem. There must be recognition that the engineer is an integral part of the system and influences the system response to external disturbances. Considering the engineer as a citizen part of the system, affecting system dynamics distinguishes this position from the honest broker role outlined in Mitchell (Mitchell 2004), which suggests that the engineer is a go-between or intermediary, rather than being directly involved in the system. The honest broker conception appears to persist with the positivist, independent role of the engineer that largely has been rejected in the philosophy of science discourse of the last 70 years or so.

What is proposed here is that there be a "Copernican revolution" in engineering practice. Just as Copernicus made a paradigm shift in realizing that the earth revolves around the sun, and Kant revolutionized philosophy through his insight that, rather than assuming knowledge must conform to reality, actually we identify knowledge to which our conceptions of reality must conform, so too must engineers change the prevailing paradigm for engineering practice. In order to engage completely in Type 3 problems, engineers must see themselves as a part of the problem and the environment in which the problem exists, not separate from it. Rather than being the detached, independent provider of a solution that is imposed upon the problem, the engineer's role needs to be one of an informed representative of the moral interests within the problem domain. The engineer must seek to provide a rational, critically-derived solution, which includes consideration of the physical, subjective, and objective elements of the problem. Engineers must also propose a set of morally-acceptable, potential solutions and implement the one with the "best" outcome. The Type 3 problems of the sustainability discourse require such solutions to be identified and implemented. The problems exist because their importance has been identified, and it is acknowledged widely that solutions must be found. To do nothing is not an option. Such a position is at odds with much current engineering practice, and the practical philosophical principles espoused here represent a new paradigm that requires engagement in the problem not only as engineers, but also as citizens.

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Chapter 12
What Do Bridges and Software Tell Us about the Philosophy of Engineering?

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Abstract One of the challenges in the emergent field of philosophy of engineering is to understand its position relative to philosophy of science. The call for a rigorous experimental methodology that has affected several fields in engineering should not make us equate good experimentation with traditional scientific experimentation. We have reason to believe that the primary role of artifacts and the human factor introduced by their designers affect the nature of experiments in engineering research and differentiate them from the traditional scientific method. We carry out our analysis with a specific focus on software engineering, a field in which the level of attention for scientific rigor in experiments has become very high in recent years.

12.1 Introduction

Philosophy of engineering is an emergent field of philosophy: the process of establishing its scope and method is still going on. One of the challenges in this endeavor is to understand the position of philosophy of engineering relative to philosophy of science. This, in turn, taps into the longstanding debate on the relation between engineering and science, because if some criteria are found that distinguish engineering from science, they might provide some clues on the nature of philosophy of engineering as a discipline.

The traditional distinction between science's "knowing that" and engineering's "knowing how" has become blurred: for example, scientific theories on the building blocks of physical reality, such as the existence of the Higgs boson, have started

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calling for more and more complex engineering work to verify them, like building a sub-atomic particle accelerator (Hacking 1983).

Such know-how is at the core of Natasha McCarthy's proposal to distinguish engineering from science (2006). The basic idea is a contrast between the critical evolution of scientific theories (ranging from complete upheavals, e.g. phlogiston in chemistry, to localized applications, e.g. Newtonian laws in physics) and a cumulative expansion of a body of engineering knowledge, possibly increased over time, but never re-written. In particular, McCarthy states that while any scientific theory may be rejected, it is not possible that we might one day wake up to find that the bridges that have been constructed according to older engineering methods have all collapsed" (McCarthy 2006, p. 49). Yet, many bridges have collapsed in the past, like the Tacoma Narrows Bridge in the U.S. State of Washington: the measures against its vertical movements in windy conditions proved ineffective, and its main span collapsed on November 7th, 1940. The repercussion of this accident was huge, and bridges have been modelled in wind tunnels ever since.

If scientific theories and engineering know-how are more and more indistinguishably intertwined, is it legitimate to equate the above-mentioned innovation in the practice of structural engineering with a change of a scientific theory? We think that the answer is no. Firstly, we follow McCarthy in recognizing that there is a significant piece of consolidated knowledge in the field, i.e. statics, which has not been put under discussion by the accident.

Secondly, and most importantly, such change in the know-how has been introduced independently from a relevant scientific knowledge. For years, the collapse of the Tacoma Narrows Bridge was considered a typical example of "forced resonance" (a match between the frequencies of the wind and the bridge's structure), while, more recently, a new explanation has been proposed based on "aeroelastic flutter" (a self-exciting oscillation due to insufficient dissipation of vibrations, Billah and Scanlan 1991). The tests in wind tunnels were not aimed at confirming or refuting candidate theories: they have become consolidated practice because they allowed for the construction of better bridges; hence, they appear to differ, at least in their purpose, from traditional scientific experiments.

We take the Tacoma Bridge accident as a starting point for our investigation on the characteristics of engineering research as a discipline. In particular, what happened in the following years with the introduction of experiments in wind tunnels provides us with the perspective we adopt in our analysis: we focus on experiments in engineering, and in particular in Software Engineering, because they seem to give us several insights that might help us in our endeavors in philosophy of engineering.

12.2 The Context: Engineering and Experiments

The term "engineering" comes with at least two different meanings: there exists a profession, in which engineers try and solve problems by designing, producing, and testing technological artifacts; and there exists a research activity in which persons who have studied engineering and possibly engineering practice or have practiced in the profession, investigate new and better ways to create such artifacts.

The focus of this work is on the latter. This view is very similar to the branch of philosophy of technology called "analytic" by Franssen et al. (2010). The main focus is on technology itself and on its researchers and practitioners, as opposed to the "humanities philosophy of technology" that is concerned with the various social, cultural, and economical consequences of technology in our society. There are several issues tackled by the analytic philosophy of technology: the relationship with science, the role of design, the methodology adopted in the discipline, the status of the created artifacts, and the ethics of technology, just to name a few.

For our purposes, we rely on the traditional meaning of engineering as the practice of technology, and in our attempt to do some analytic philosophy of engineering, we assume a methodological perspective and concentrate on the nature of experiments in engineering research because we consider this topic promising in the task of clarifying the nature of this discipline, especially with respect to its relation with traditional science.

In fact, one of the most significant issues when it comes to engineering research is its relation with scientific research: whenever a result is obtained in engineering, it is legitimate to ask the question whether such result is "scientific" or not. Either possible answer seems to pose interesting problems.

If the "scientificity" of a result makes it a legitimate product of engineering research, does this mean that engineering research is scientific research? Is then engineering a subfield of science? Or is it applied science, as already stated in the past by the likes of Mario Bunge (1966)? Is then philosophy of engineering just a special kind of philosophy of science?

On the contrary, to state that engineering research is not scientific sounds detrimental. If it is not scientific, how can its results be considered reliable? Consider again the Tacoma Bridge accident and the methodological innovations introduced on the basis of a possibly wrong scientific explanation. They stuck around and went on to become part of standard civil engineering practice even after a new scientific hypothesis was introduced to explain what caused the bridge to collapse. What kind of motivations justified such continuation if not scientific ones?

In what follows, we will show how a fully-fledged rigor is indeed applied in many experiments in engineering, which can be considered to be derived from the scientific tradition, but that not all the characteristics and the factors that affect and guide research in traditional scientific disciplines can be imported into engineering in a straightforward way. In particular, among all the various subfields of engineering, although our discourse took off from massive products of Civil Engineering like bridges, we will focus on Software Engineering and its experiments on how to improve the creation of intangible artifacts like computer programs. We choose this particular field, in which experiments gained a significant role in recent years, as shown below.

12.3 The Case of Software Engineering

Software Engineering is the subfield of Computer Science aimed at the study and application of techniques for the design, development, operation, and maintenance of software. As any computer system must rely on software, it is clear that Software Engineering is a vast discipline that intersects many, if not all, other subfields of Computer Science. One reason to consider Software Engineering important for our analysis is that as a subfield of Computer Science, the long-standing debate on the scientific nature of the latter (Tichy 1998; Morrison and Snodgrass 2011) inevitably involves also the former.

Such involvement is all but straightforward. Computer Science is a vast discipline that includes subfields that differ so greatly from each other with respect to subject matter, scope, methodology, and so on, that the existence of Computer Science as a unitary discipline can be called into question, and it is not even clear whether general claims made about it can be considered legitimate. The reader should refer to Matti Tedre's thorough overview of the problem (Tedre 2015). The nature of Computer Science as a discipline lies beyond the scope of this work, but some points made in such debate are particularly important for our analysis of methodology in engineering research.

Firstly, several authors considered the scientific nature of Computer Science incompatible with the presence of Software Engineering among its subfields: for instance, Juris Hartmanis (1993), George McKee (1995), and Frederick Brooks (1996) all shared the view that a synthetic perspective, guiding researchers toward the creation of products rather than the discovery of laws of nature, was clearly showing the engineering (and not scientific) nature of the discipline. While this may be problematic for a so-called "science", it should not have any repercussion on an "engineering"; on the contrary, such criticism might be interpreted as a recognition of the primary role played by Software Engineering in the context of Computer Science.

If this position seems to draw a divide between the two disciplines, another argument emerged concerning the methodology adopted in the research. Interestingly, this time there is no distinction about their scope; research quality seems to be the only important factor. Tedre himself writes, "The most common complaints about the quality of research in computer science revolved around software engineering (p. 370)", which seems to imply that the science versus engineering issue is somehow set aside.

In particular, Zelkowitz and Wallace (1997) provided the most complete evaluation on research quality in Software Engineering. They examined 612 papers published in the IEEE journals *Transactions on Software Engineering* and *Software*, and in the proceedings of the "International Conference on Software Engineering" in the years 1985, 1990, and 1995. The authors proposed a taxonomy of experimental data collection techniques, ranging from "no experimentation" at all to "replicated experiments" to classify the papers and compare them with works published in journals of other disciplines (i.e. *Measurement Science and Technology*, *American Journal of Physics*, *Journal of Research of the National Institute of Standards and Technology*, *Management Science*, *Behavior Therapy*, and *Journal of Anthropological Research*).

The conclusion of this admirable work is that, although the analysis shows that the trend is moving in the direction of a greater attention towards a rigorous experimental methodology, about one third of the Software Engineering papers had a weak form of experimentation (called "assertion" by the authors) that favors the proposed technology over possible alternatives, while in the other examined fields the relevant figure lies between 5 and 10%. Showing that the experimental rigor in Software Engineering was lower than in other scientific disciplines seemed to confirm the position of certain critics that argue that its engineering character was the main obstacle between Computer Science and the status of full-fledged science, but it may also be viewed as an attempt to call for a more rigorous methodology in the discipline.

To summarize, among the several doubts with respect to the scientific status of Computer Science, one widespread position was concerned with its engineering-oriented subfield. The critics were not only pointing at an arguable distinction between proper science and engineering, but independently from the subject matter of these disciplines, they considered the methodology adopted in Software Engineering lacking in rigor in comparison with other sciences. We can only speculate on why Software Engineering became the center of negative attention among all subfields of Computer Science; the nature of the subject matter of Software Engineering research may be somehow involved. If Theoretical Computer Science, which deals with algorithm complexity, automata, and so on, necessarily follows the guidelines of traditionally rigorous disciplines like mathematics and logic, such instruments can support only part of what is carried out in Software engineering.

Given a problem, the ultimate aim of Software Engineering is to write a program that, run on a computer, solves such a problem. The fact that the solution must be a piece of software naturally restricts the scope of the problems that is meaningful to tackle with Software Engineering. Nevertheless, the context of this discipline is notably vast, as there are several degrees of freedom depending on the choices made with respect to the entities involved in a typical scenario:

- The *requirements* describe the problem in terms of what is required of the solution; such description can be provided in a natural or a formal language, and at different levels of detail;
- The *programmer* (or team of programmers) is responsible for the creation of the software, by first conceiving an algorithm, and then turning it into a program;
- The *programming paradigm* is the view that underlies the way the software is going to be written: with a functional paradigm, for instance, all operations that a program is to perform are modeled as functions, whereas the object-oriented paradigm views such operations as actions taken by different objects, that is, independent subparts that constitute the program;
- Given a paradigm, a programmer can have more than one *programming language* to choose from: for example, C++, Java, and Python are all object-oriented languages;
- The *program* itself can be written in different ways in the same language, depending on the structure by which the included operations are organized;

- Once a program is written, a *testing* process must be carried out, to ensure that it fulfills the requirements it was created for;
- Finally, if more programs are available to solve the same problem, a *benchmarking* technique can be used to assess which program achieves the goal with the least resource consumption in terms of computing time and computer memory.

A significant task, perhaps the most significant in Software Engineering research, is to establish criteria that help make the best choices regarding the above mentioned entities, in terms of selecting, with respect to the given problem, the most suited requirement specification language, the most skilled programmer, the best fitting programming paradigm and language, and so on. All these activities are heavily human-centered, and following a rigorous method to do research on this kind of practice becomes particularly critical. Whether under the pressure of methodological criticism or not, Empirical Software Engineering was born as a discipline to meet such need for rigor: in 1996 the first volume of the *Empirical Software Engineering* journal was issued (Basili 1996), and in 2002 the first "International Symposium on Empirical Software Engineering" (IEEE 2002) took place in Japan.

Such initiatives are not to silence all criticisms: for instance, by examining the articles published in the journal, one can notice that "empirical" and "experimental" are often used as synonyms, which shows that the conceptual framework could use some further refinement. Moreover, 5 years after the journal was born, researchers like Juristo and Moreno (2001) still deemed it necessary to provide a list of caveats in a book on experimentation in Software Engineering, e.g. a lack of training in the importance and meaning of the scientific method, a lack of statistical training to understand how to analyze the data of an experiment or how they were analyzed by other researchers, a lack of interest in publishing empirical studies conducted to check the ideas of others, etc. Let us illustrate in the following a work that effectively addresses many of these issues. Naturally, one good paper does not reflect an actual trend in a discipline, but it is at least a proof of the fact that the type of methodology called for by Juristo and Moreno is possible and has actually been practiced in some research groups.

12.4 An Experiment in Empirical Software Engineering

Let us focus on a case that best embodies the issues we are tackling in this work. Cepeda Porras and Guéhéneuc (2010) have recently proposed an experimental comparison between the Unified Modeling Language (UML) collaboration notation and three other proposals: pattern-enhanced diagrams (Schauer and Keller 1998), stereotype-enhanced UML diagrams (Dong et al. 2007), and "pattern:role" notation (Gamma 1997), in order to verify which notation provides the best support to software developers in three basic tasks in design pattern comprehension. In particular, UML collaboration notation has been compared with each of the other three notations in the context of three sets of controlled experiments, aimed at collecting data to compare developers' performance in (1) identifying all the classes of objects in a program participating in a given design pattern, (2) identifying the role that a class plays within a specific pattern, and (3) identifying all the design patterns in which a class participates.

Data were collected for 24 subjects, all involved in M.Sc. or Ph.D. studies at the authors' department. Each subject tackles the three tasks over two representations with different class densities (one representation has 15 classes, the other has 40). For every task and every representation, the subject must answer a question. Performance is measured in terms of percentage of correct answers and the subjects' effort to perform the tasks. The effort is measured by means of an eye-tracking system, aimed at detecting how much time the subject's glance lingers on different areas of the diagram shown. The quality of the performance is defined in terms of the ratio between the time spent on the areas of interest (showing the classes that are relevant for the correct answer) and the overall time spent on the diagram: the closer to 1 is the ratio, the better is the performance. To avoid head movements and ensure the uniformity of the measurements, all subjects were put in a dentist chair with a travel pillow for neck support.

The authors report that, for the diagrams with 15 classes, the UML collaboration notation outperformed the stereotype-enhanced UML diagrams in task 1, whereas the opposite result was obtained in tasks 2 and 3. No statistically significant differences were detected in the comparison with the other two types of notations in any task. It is additionally reported that the level of knowledge of design patterns could significantly influence the performance of users tackling task 3 with the UML collaboration notation and the "pattern:role" notation. The only statistically significant result obtained with the diagrams with 40 classes is that in task 1 the UML collaboration notation performs better than the stereotype-enhanced UML diagrams. Moreover, it is pointed that such results may be strongly influenced by the readability (or lack thereof) of the diagrams with 40 classes.

Let us analyze this experiment from a methodological point of view, keeping in mind the traditional principles underlying scientific experimentation. In science, experiments can test theories, verify or falsify hypotheses, help choose between rival hypotheses, enable the application of tested theories, and help improve instruments (Franklin 2012). To guarantee the universality of their results and their independence from environmental factors, experiments must be *repeatable* at different times and places, and they must be *reproducible* by other researchers. To ensure such characteristics, *measurements* must be made with the maximum rigor possible, and a *precise language* must be used to describe the procedures and the obtained data. Finally, the experimental data must be interpreted so to derive the correct implications in *justifying* and *generalizing* the results whenever possible. These principles exemplify the modern concept of experimental method, as developed during the Scientific Revolution in the seventeenth century (Westfall 1971).

How do Cepeda Porras and Guéhéneuc perform with respect to these principles? Undoubtedly well for the most part: the experiment they performed is described in such detail and with such clarity that, provided with analogous instruments, any researcher could reproduce it and repeat it; moreover, measurements are taken with high-precision instruments that guarantee the quality of the experimental data, which have also undergone a thorough statistical analysis. Zelkowitz and Wallace would have surely classified their proposal among the examples of "good" Software Engineering experimentation in their survey.

Cepeda Porras and Guéhéneuc's work appears to be more problematic when it comes to the principles of justification and generalization, an issue neglected by Zelkowitz and Wallace but tackled by other researchers concerned with the scientificity of Software Engineering. Juristo and Moreno, whose methodological requests are indeed met by this experiment, have yet another caveat: that is, the lack of an explanation of the obtained results; many researchers fail to provide a solid justification of the observed phenomena that might pave the way for a general principle with the potential to expand the knowledge in the field in which they perform their experiments. Hannay et al. (2007) provide a review on the use of theory in 103 articles reporting Software Engineering experiments published in journals and conferences in the 1993–2002 decade. Of these 103 works, only 24 attempt the formulation of a theory; they use a total amount of 40 theories to explain the cause/effect relationship under investigation, but it is shown that such theories are never used as frameworks in which different authors discuss the same issues across articles. In other words, Software Engineering researchers rarely advance a theory, and even if they do, there seems to be not one theory that different research groups are working on independently. Cepeda Porras and Guéhéneuc are no exception; they do not refer to any general theoretical framework into which their results are to be inserted.

Some legitimate questions may be raised. Is one paper a significant example for a general assessment of a discipline? After all, the very work of Cepeda Porras and Guéhéneuc constitutes a brilliant example of high-quality experimental methodology that the survey by Zelkowitz and Wallace showed to be lacking in Software Engineering research in 1997. Is it unreasonable to expect that other notable works will disprove or at least be a counterexample for Hannay, Sjøberg, and Dybå's more recent survey on the lack of generalization and theory formation? Should we start yet another thorough analysis of more recent Software Engineering papers? Surveys are always useful, but the problem with the justification and generalization principle may not only be a contingency that can be overcome with improvements in the research activity, but it may point at some intrinsic factor that characterizes engineering research.

12.5 Clues on the Nature of Engineering Experiments

Let us consider the experiment on the UML collaboration notation once again. The hypothesis that the results obtained with the diagrams with 40 classes may have been strongly influenced by their lack of readability points at a significant issue: subjectivity. Readability is not an intrinsic quality of a diagram: it is significantly influenced by the effects that such a diagram has on the human subject in front of it. Hence, the question naturally rises on whether we would be observing the same results with a different group of subjects. The degrees of freedom, or the factors potentially influencing the course of the experiment are then extremely numerous: not only can there be diagrams based on different classes, or a different number of classes, or different design patterns, but also the personal history, disposition, aptitude of the subjects should be taken into account.

Obviously, we are not stating that generalization is impossible in any experiment involving human subjects: there exist indeed some general principles in human-centered disciplines that are accepted by the relevant research community. In Evidence-based User Experience research, for instance, it is now consolidated knowledge that the best outcome in terms of balance between use of resources and reliability of results comes from performing tests with no more than five users (Nielsen and Landauer 1993). Analogously, performing more experiments with different diagrams and different group of subjects, Cepeda Porras and Guéhéneuc might conclude that, in general, the readability of a UML collaboration diagram is lost when the number of featured classes is more than a certain threshold n.

Due to the above-mentioned subjectivity, such result could not be used in the same way physicists do with, for example, the value of the rest mass of an electron (9.109×10^{-31} kg). Although all these figures can be considered as average values obtained by means of a sufficiently long series of experiments, the diagram readability threshold would be characterized by a greater variance because it would be influenced by a much higher number of factors depending on the human subjects than the intrinsic physical properties determining the mass of an electron.

We can recognize here a distinction between this kind of experiment and traditional ones in physics or chemistry: the objects under observations are different in that they are not natural objects or phenomena, but processes human beings follow to create artifacts.

On one side, the plethora of variance inevitably introduced by the human factor makes the generalization of the results much harder. On the other side, the fact that the final result is supposed to be a working artifact may relieve researchers from the pursuit of generalization at all costs in favor of other objectives. If engineering research has the ongoing objective of finding more efficient ways to build effective artifacts (i.e. technological progress, in Henryk Skolimowski's terms Skolimowski 1974), then the issues at stake are not about the discovery of general truths, but are pragmatic (e.g. economic, ethical, societal).

Let us imagine a situation in which a team of software engineers needs to redesign part of a computer program to substitute a design pattern with a new one for efficiency reasons. According to the results of Cepeda Porras and Guéhéneuc, the team should use the UML collaboration notation to identify all the items in the program that are involved in the soon-to-be obsolete design pattern. What if all the members in the team have 5 years of experience of working with pattern-enhanced diagrams and, instead, are rather unfamiliar with UML collaboration notation? What if the number of classes involved in working on the design pattern is more than 100, and the resulting diagram turns out to be completely unreadable?

This example is not to show that experimentation in engineering is meaningless, but that experimental results in the literature may have been obtained under conditions that are difficult if not impossible to reproduce (e.g. the persons involved are different) and, more importantly, that are not always those in which researchers and practitioners are currently interested (e.g. the software to work on is different). The extreme specialization of artifacts in Software Engineering is driven by the requirements they are meant to meet, and the peculiarity of their characteristics and the pragmatic constraints imposed by the circumstances compel the designers to quickly take decisions based on common sense and their experience, or to engage in further experimental activity to obtain rigorous results that are locally relevant.

Thus, the merit of Cepeda Porras and Guéhéneuc is not to have shown once and for all which type of diagram software engineers should use for the above-mentioned tasks, but to have illustrated in detail an experimental procedure they may follow when such a decision needs to be taken. However, this also means that the results of an experiment that can be considered to meet all the strict methodological criteria cannot be used by other researchers or by practitioners in a straightforward way: it will be always necessary to carefully adapt the described procedures to new scenarios in which experimental verification is called for.

12.6 Conclusions

This work is meant to help take some steps in the development of the emergent discipline of philosophy of engineering. Given the long standing debate on the relation between engineering and science and the more recent attention to experimental rigor that flourished in several fields of computer engineering, we advocated for the assumption of a methodological perspective in this endeavor, because we deemed it very promising to analyze the similarities and the differences in how experiments are conducted in engineering with respect to the traditional scientific method.

In particular, we started our discourse from the Tacoma Narrows Bridge accident, one of the most striking examples of the fact that the search for scientific knowledge might not be a priority in engineering experimentation. We then shifted and narrowed our focus to Software Engineering, the subfield in which the call for a scientific rigor in the methodology has been the strongest in recent years, to the extent that journals and conferences were created with an explicit reference to this issue.

The analysis of a work from this field showed us that a strict adherence to the rigor traditionally characterizing scientific experiments has also been reached in some areas of engineering research. However, a straightforward import of traditional experimental principles does not seem possible because of problems with the principle of generalization: given the wide range and diversity of conditions in experiments that can be conducted and because of the variance that comes with the human factor that always plays a significant role, it is difficult to extend the validity of the results to a context larger than the very specific setting in which the experiment was carried out.

The focus on the creation of artifacts, which characterizes engineering as a discipline, frees researchers from the burden of the search for general truths on the one side, thus making the problem of generalization less critical. On the other side, if artifact designers want to take advantage of the research results in the literature, then a very careful experiment replication process must be carried out that takes into account both similarities and differences between the settings and that must be guided by the requirements the artifact to be created must meet.

Whether our analysis can be applied to all fields of engineering remains to be seen. Nevertheless, if the points made so far about the problems in generalization are relevant for types of artifacts so markedly different from each other like bridges and software, then the path seems promising. Indeed, the considerations that we presented about the design of computer programs can be made also for the artifacts of Civil Engineering, although some issues, especially those connected with the human factor, may be less critical when it comes to bridges, as their quality relies more on physical properties of materials (and, thus, on natural phenomena) than software, which is comprised of operations decided by its designers.

We are still at the beginning of a long path, which includes a deeper analysis on the nature of engineering artifacts and how it affects the experiments that researchers conduct when they intend to establish a rigorous methodology that is inspired by the traditional scientific disciplines but must be adapted to a different context in which universal truths give way to solutions to problems. Our hope is to give some contribution along the way to the conceptual framing of philosophy of engineering.

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Chapter 13
Herbert Simon Meets Billy Vaughn Koen and Joan van Aken: From Sciences of the Artificial to Engineering Heuristics and Design Propositions

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Abstract Herbert Simon's perception of the fundamental unity of design activities and the associated notion of sciences of the natural and of the artificial are put into dialogue with Billy Vaughn Koen and Joan van Aken through the device of "three blind certainties": (1) that engineering is applied science; (2) that engineering is one of the sciences of the artificial; (3) that the advancement of engineering comes from the advancement of science. Simonian vocabulary is a stepping-stone for these three blind certainties. Koen offers a Rortyan redescription that redefines the possibilities of our understanding of engineering, proposing a vocabulary of his own to expose these certainties. Van Aken qualifies, but reaffirms these certainties, refining Simonian vocabulary to broaden its reach in support of an agenda for design research. As Koen is rarely perceived in this light, some final remarks clarify his relevance, and then the dialogues between Simon and Koen, and Simon and van Aken are adjudicated.

13.1 Introduction

Herbert Simon's landmark 1969 *The Sciences of the Artificial* (3rd ed. 1996) argued for the unity of all design activities, crossing disciplinary boundaries to make explicit their shared nature. He distinguished two worlds; that of the natural and the artificial, each of which would have its own sciences, and thus engages in an academic-political debate. His goal was to offer an *apologia* for design activities, to declare they should be valued as much as the natural sciences, though neither identical in method or in content, nor inferior in worth or academic respectability. His was an unequal and doomed struggle at a time when physics and chemistry ruled

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knowledge production and were seen as the pathfinders of Vannevar Bush's (1945) *Science: The Endless Frontier.* Simon's Nobel Prize derives from his contributions to the decision-making process of economic organizations. His writing on the sciences of the artificial won a measure of academic recognition, but his proposals for a curricular reform of design teaching and learning did not. What has remained is the understanding that design has to be a science to gain academic respectability. What does all this mean for engineering?

Attempts at an answer necessarily engage three blind certainties: (1) that engineering is applied science; (2) that engineering is one of the sciences of the artificial; (3) that the advancement of engineering comes from the advancement of science. A prime task of contemporary philosophy of engineering, in which design is central, is to question such truths as these that are maintained by inertia. Two authors help question these certainties: Billy Vaughn Koen and Joan van Aken. Koen exposes them: *all is heuristics*, and engineering is not science, although it may adopt science as one of its heuristics. Van Aken renews them, subdividing the Simonian sciences of the artificial into *explanatory* and *design* sciences. Remarks on the relevance and opportunity of Koen's contribution and an adjudication of van Aken's and Koen's dialogue with Simon close the text.

13.2 Simon Revisited

Simon offers two capital propositions that are alluded to those above. First, he distinguishes two different but equally worthy types of *science*; those of the natural and those of the artificial. Second, he acknowledges the unity of a number of disciplines and practices as sharing the nature of being *design activities.*

> A natural science is a body of knowledge about some class of things, objects or phenomena in the world: about the characteristics and properties that they have; about how they behave and interact with each other. (Simon 1969/1996, p. 1)

> [Y]ou will have to understand me as using "artificial" in as neutral a sense as possible, as meaning man-made as opposed to natural.… We speak of engineering as concerned with "synthesis," while science is concerned with "analysis." Synthetic or artificial objects and more specifically prospective artificial objects having desired properties are the central objective of engineering activity and skill. The engineer, and more generally the designer, is concerned with how things ought to be—how they ought to be in order to attain goals, and to function. Hence a science of the artificial will be closely akin to a science of engineering but very different …. (Simon 1969/1996, pp. 4–5)

And:

> Engineers are not the only professional designers. Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of

> engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design. (Simon 1969/1996, p. 110)

It can be seen how Simon serves as a stepping stone to our three questionable certainties: (1) that engineering is an application of science for given purposeful aims; (2) that the science of engineering is queen of the sciences of the artificial; and (3) that advances in engineering are advances in the sciences of the artificial.

13.3 Rupture and Continuity: Simon Meets Koen and van Aken

The relevance of a meeting is not restricted to the strength it might add to preexisting understandings. Meetings can be important and fertile precisely when they lead to rupture, when they lead to the deconstruction of established truths and to the formulation of new perspectives, discourses, or just pose new questions. Such is the case of the meeting between Billy Vaughn Koen and Herbert Simon, with Koen arguing that engineering is not science, but heuristics.

Simon establishes the identity of engineering as a result of the "synthetic or artificial" objects that it produces in pursuit of a given goal, and understands that this is a kind of science. Koen argues that engineering is defined by its method, not by the objects it produces. For Koen, the method of engineering is "the use of heuristics to cause the best change in a poorly understood situation within the available resources" (Koen 2003, p. 28), understanding heuristics as "anything that provides a plausible aid or direction in the solution of a problem, but is in the final analysis unjustified, incapable of justification and potentially fallible" (Koen 2003, p. 28). This argument strikes at the very foundations of Simon's three certainties about engineering. If, as Koen says, engineering uses anything that *might plausibly* help achieve its ends, it uses more content and skills than those of science, and hence one cannot say (1) that engineering is applied science. If, as Koen says, engineering is the opportunistic use of heuristics, then it has no Popperian demarcation criteria (Popper 2002), cannot be taken *per se* as scientific, and hence one cannot say (2) that engineering is one of the sciences of the artificial. If, as Koen says, any heuristics are *ultimately* unjustifiable and fallible, the advancement of engineering follows the success and failure of engineering projects, which may or may not correspond to advancements in science, and hence one cannot say that (3) the advancement of engineering comes from the advancement of science.

When meetings add to preexisting understandings, they can do more than confirm old certainties; they can refashion them to new perspectives, add issues, renew explanations, and enlarge contents. Such is the case of the meeting between Joan van Aken and Herbert Simon, with van Aken arguing that design is science and includes engineering.

Simon's sciences of the natural and of the artificial are concerned with the characteristics, properties, behaviors, and interactions of "objects or phenomena in the world" and with "prospective artificial objects" that aim at the fulfillment of a given goal, respectively.

For Joan van Aken, Simon's natural/artificial binary is insufficient to circumscribe the key issue related to design. Van Aken proposes a new perspective for the non-"empirically void" sciences: the binary "explanatory/design", a distinction "strongly inspired by Simon's *The Sciences of the Artificial"*. In a tripartite division of "scientific disciplines," Van Aken further distinguishes what he calls "formal sciences" "such as philosophy and mathematics", but these are "empirically void", and are not the object of his considerations (van Aken 2004, p. 224). For van Aken, the mainstream of research in design science aims "at describing, explaining and predicting in order to understand the setting of construction or improvement problems and to know the properties of the 'materials' to be used"; however, its ultimate mission remains to "develop design knowledge, i.e., *knowledge that can be used in designing solutions to problems* in the field in question" (van Aken 2004, p. 225, emphasis in the original). He remarks that his definition is more inclusive than that of Simon, in that he deals with both construction and improvement problems, while "Simon primarily discusses construction problems" (van Aken 2004, p. 242, note 5).

Van Aken, along with Hans Berends and Hans van der Bij, applies this understanding to the research practices of academic and professional schools, distinguishing their mainstream paradigms. The explanatory paradigm would be "based on Lakatos" (van Aken et al. 2012, p. 60; they use Lakatos' chapter in Lakatos and Musgrave1970/1991; cf. Lakatos 1980), while the design paradigm would articulate both explanatory and designerly components for diagnosis and the identification of alternative treatments:

> Engineering research produces not only generic explanatory knowledge on, say, the properties of materials one can use to build a bridge but also generic design- oriented knowledge on alternative constructions for bridges, such as solution concepts or exemplary designs. Generic knowledge in both medicine and engineering is to a large extent developed on the basis of series of similar cases in which the knowledge in question is developed and tested. (van Aken et al. 2012, p. 62)

Van Aken's stand on the three certainties is not a rupture. He qualifies the first, (1) that engineering is applied science, saying "I prefer to avoid the term 'applied sciences', as this term suggests that the mission of these sciences is merely to apply the basic laws of the explanatory sciences". He praises the "impressive body of knowledge developed by the design sciences themselves" (both passages, van Aken 2004, p. 225). For him, the design sciences, engineering included, are not merely a non-scientific application of explanatory sciences; there is science in design, with its own theoretical-explanatory- designerly *corpus*. Van Aken argues that medicine, management, and engineering are design sciences, and hence, implicitly agrees with proposition (2), that engineering is a science of the artificial under his reformed formulation. As for the advancement of engineering and of all design disciplines, van Aken clearly supports that it is embedded in (3) the advancement of explanatory and design sciences by grounding and field- testing design propositions.

13.4 Final Remarks

As non-native English speakers, it puzzles us that Koen's message on the method of engineering (Koen 2003) is so often disqualified at first blush, misunderstood or reduced to a tautology. First blush disqualification seems to stem from a commonplace understanding of heuristics as *mere* rules of thumb. This understanding forgets what the *Webster's Collegiate* or the *Oxford English Dictionary* (OED) records: The use of heuristics as synonymous with *ad hoc* or tacit approaches is circa 1960, according to the OED, whereas in philosophical tradition, heuristics has a much broader meaning.

For us, Koen's use of the term "heuristics" has a philosophical intent. Therefore, it is reasonable to understand his use of heuristics according to the philosophical tradition, which agrees with the first meaning to be found in dictionaries, as anything that might lead to solving a problem or, as Koen proposes, "anything that provides a plausible aid or direction in the solution of a problem, but is in the final analysis unjustified, incapable of justification and potentially fallible" (Koen 2003, p. 28).

Misunderstanding Koen admits variety, but what concerns us most is the attempt to read his propositions with a reduced understanding of heuristics. Such a reading sets aside anything that is not rule-of-thumb in engineering, leading to the mistaken conclusion that engineering is heuristics plus a lot else that is not heuristics. This conclusion fails to appreciate Koen's extensive efforts at showing that all knowledge we possess is, and should be acknowledged as, heuristics. He weaves a delicate tapestry with the items of his presentation: arithmetic, mathematics, deduction, certainty, position, logic, truth, progress, causality, consciousness, physical reality, science, perception, and argument. Koen's philosophical intent is dramatically expressed in the concluding remarks of "Engineering, Philosophy and the Universal Method": "*What we most desperately need is a New Renaissance Philosopher to engineer our world based on the search for the best heuristics for human survival*" (Koen 2003, p. 226, emphasis in original). Such an ambitious and comprehensively woven construct is incomprehensible if composed only of "rules of thumb".

Finally, to grasp Koen's thesis in short form as "engineering heuristics are those heuristics engineers use" does offer the appearance of a tautology, and its symmetry is seductive. This understanding is not a perversion of what Koen says, only an instance of losing sight that a sentence is not just what it says, but what it provokes us to think about as we hear it. It requires a literal fundamentalist to declare this sentence a tautology. Koen's provocation aims at not letting us confine engineering to any one given set of heuristics, not even to the inventory of all heuristics engineers have ever used. The heuristics engineers use is an open set. Hence, if the question were to be, "What are engineering heuristics?" the answer would be, without any tautology, "Engineering heuristics are heuristics engineers use." They are only *engineering* heuristics after this use. An unsuspected consequence is that *anything* that engineers use are heuristics as far as engineers are concerned.

Engineers may use science, but they do so by taking it as just another heuristic. Does this mean that the reliability or accuracy or predictive quality of scientific knowledge is not considered when an engineer chooses to use it? Of course not. Engineers are educated in science and in all the various threads of Koen's tapestry. However, engineers are not educated for science—or they would be scientists, and this is not a tautology either. Good engineers use science without prejudice, as heuristics. They remain alert to the idiosyncrasy of their individual projects. In the pursuit of their projects, they may use any science or any non-science as heuristics. And it is a hallmark of good engineering that engineers may choose whichever seems to promise the best results, blending different heuristics, even choosing non-science over science if that promises a better result. It might even be said that the art of the engineer is the ability to fashion a blend that achieves the best change possible. The primary concern of engineers is to carry the project through. Engineers are both practitioners, willing to borrow heuristics from *anyone,* including scientists, and researchers, capable of creating heuristics *of their own*, without becoming scientists as a result.

Van Aken writes prose; Koen makes poetry. Van Aken meets Simon under the banner of continuity. He lends new breadth to Simon's propositions, enlarging horizons, and making possible additions to the discourse. Simon's original vocabulary is renewed, the original intent expanded, seeking to make explicit the scientific content of design sciences. He supports a research and intervention agenda that aims to bridge the so- called "research-practitioner gap" of management. Van Aken emulates the design process of engineering in management (van Aken et al. 2007, 2012). For him, the content and method of design sciences are the key, articulating how knowledge in management should be sought, obtained, and disseminated (Denyer et al. 2008). Management and engineering would be both the application of natural sciences and of explanatory and design sciences of the artificial, as well as the production of a body of scientific knowledge of their own.

Appeal to the philosophy of Richard Rorty can provide another way to understand the Koen-Simon rupture. Rorty defended a version of pragmatism in which scientific and philosophical methods are no more than contingent vocabularies that people alter and adapt over time according to their utilities. In accord with Rorty's view, Koen re-describes Simon's vocabulary, giving birth to a new vocabulary of his own, hoping "that y the time [he] has finished using old words in new senses, not to mention introducing brand-new words, people will no longer ask questions phrased in the old words" (Rorty 1989, p. 78, gender changed to refer to Koen). Simon's words are subverted and new terms arise through Koen's effort to offer a new interpretation of the world of engineering and engineers.

Following the same Rortyan inspiration, we decline to adhere to perennial metaphysical truths as self-standing authoritative arguments. Rather, we agree that "what counts as a possible truth is a function of the vocabulary you use, and what counts as a truth is a function of the rest of your beliefs" (Rorty 1989, p. 172). Therefore, while we question them, we do not wish to amend certainties nor to replace them. Neither do we wish to assess the perspectives of Simon, Koen, or van Aken as true, false, or somewhere in- between. In Rortyan terms, truth is not "out there", but inside the vocabularies we use. In this perspective, the main issue here is to appreciate vocabularies that enable us to establish fruitful relationships with the world and, particularly, meaningful relations with the world of engineers.

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Part III

Philosophical Perspectives on Engineering History

Chapter 14
Early Chinese Engineering Education: Influence and Disappearance of the Fuzhou Shipping School

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Abstract Early engineering education in China has influenced later practice. This article takes the Fuzhou Shipping School as a case study, examining it status, basic characteristics, and impact on engineering education in China during the Westernization Movement. It shows how engineering education incorporated practice that influenced other aspects of Chinese society, and suggests a general framework for understanding the development of subsequent engineering education in China.

14.1 Introduction

Modern engineering education in China emerged with the transplanting of modern Western industrial education. This transplanted education aided Chinese modernization and was stimulated by external pressures from the Western colonial and capitalistic expansion into China. As Tao Xingzhi has written,

> Since 1820 to 1860, we always failed in contact with foreigners, our weaknesses were gradually exposed, and the advantages of foreigners were gradually identified. As a result, we were forced to consider why we were so weak and they were so strong. They were strong because of their diplomacy, so we set up the Tong Wen School; they were strong because of their navy, so we set up the Navy and Vessel College; they were strong because of their manufacturing industry, so we set up technical schools; they were strong because of their army, so we set up a military academy; they are strong because of their science and technology, so we set up science colleges. (Tao 1991, p. 1052).

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14.2 Brief History of the Fuzhou Shipping School (福州船政 学堂)

What is commonly called the Fuzhou Shipping School was initially a uniquely Chinese amalgam of foreign language learning, vocational skills education (e.g., in carpentry and horticulture), ship construction (and operation), and naval academy (maritime navigation and weapons training). The school was established in Fujian province in January 1867 as an addition to the Fuzhou Shipyard. Although the Fuzhou Shipyard itself was still in an embryonic stage, the new school quickly opened and recruited students. The Fuzhou Shipping School was the first modern Chinese naval academy and the first to introduce Western science and technology teaching materials and educational systems. Continuing the work of the Westernizing Group centered around Zeng Guofan and Li Hongzhang, which established the Capital Tongwen Foreign Language School and other foreign language institutes, the Shipping School was the earliest to train technology students in modern naval construction, operation, and management.

The school was composed of two units at slightly different locations: a *qian* (前 means 'front') school and a *hou* (后 means 'back') school. In the *qian* school, also called the French or manufacturing school, students studied the French language and literature along with steamship construction, industrial painting, and horticulture. In the *hou* school, also called the English school, students studied English language and literature along with piloting, shipbuilding, and engineering. Both school programs were on a higher education level for that time, and in this sense the Fuzhou Shipping School is a predecessor of modern engineering education in China.

The Xinhai Revolution broke out in 1911, giving birth to the Republic of China. Soon after, in October 1912, under jurisdiction of the Department of the Admiralty, the navy separated the Fuzhou Shipping School from the Fuzhou Shipyard. The school was then further divided up into three units—a design and construction school, a naval management school, and a practical arts school—thus terminating 40 years of the Fuzhou Shipping School. From 1867 to 1912, the Fuzhou School educated large numbers of technical experts who became influential in Chinese public affairs during the late Qing Dynasty, including high-ranking officers of the navy, engineers, writers, and scholars. The Fuzhou influence was greater than all foreign language schools founded by the Westernizing Group, primarily because it was the first to introduce modern Western science and technology into contemporary Chinese education. How is it that such an influential engineering education institution should suddenly cease to exist, especially when there was such a need for engineering to contribute to development in the new republic?

14.3 Further Historical and Cultural Context

Following the Opium Wars (1839–1942 and 1856–1860), China began a process of modernization and coastal defense engineering in order to “learn Western skills to fight against Western countries.” During this period, the main goal of coastal defense engineering was to protect from foreign invasion from the sea, which had gradually become a central topic of discussion for some advisers in the Qing government. As the Chinese general and statesman Zuo Zongtang had argued, “to protect against threats from the sea while receiving its benefits, we must establish a navy; to establish a navy, we must set up bureau to supervise and build ships.” This means “once you master the manufacture of steam warship technology, foreigners will not be the only ones who are good at this technology” (Zhongguo shi xuehui 1961, p. 6).

At that time, then, Zuo Zongtang and others viewed the westernization of schools and the development of new types of expertise as necessary for the creation of a modern Chinese military industry. When the Fuzhou Shipping School was founded, Zuo made clear that the goal was to train China’s shipbuilding and maritime management skills in order to promote technological independence and escape foreign domination. “If China wants self-improvement, it is necessary to learn foreign weapons. Wanting to learn foreign weapons, it is necessary to study how to make weapons. We need to learn the methods foreigners use to make weapons, but we do not need to depend on the foreigners”.

Each major in the Shipping School was a relatively complete curriculum. Foreign languages (English or French), arithmetic, and plane geometry were required courses common to all majors. In addition, each major had its professional foundation courses, some of which overlapped with others. For example, manufacturing majors focused their studies on calculus, physics, mechanics, and internships. The *huishi* (绘事) (mechanical design) major studied descriptive geometry, graphics, turbine design, and plant operations. The navigation professionals focused on the study of nautical astronomy, navigation theory, and geography. After 3 years of theoretical study, navigation students were required to take part in more than 2 years of practical training called “ship practice.” Engineering majors studied mechanical drawing, offshore mechanical operations, machine installation, and instrumentation use (Pan 2006, pp. 14–18).

The Fuzhou Shipping School curriculum clearly moved away from the pedagogy that dominated traditional Confucian classical education in the “Four Books” and “Five Classics”, which emphasized memorization and maintenance of the status quo. At Fuzhou the emphasis shifted instead to practical learning and application or the combining of theory and practice. In this it followed a change that took place as well in the imperial civil service exam, which reduced the importance of the memorization of classical texts and shifted toward training in public professional responsibilities, specialization, and practical skills. With a variety of practical courses and trainings, cohort after cohort of technical and engineering personnel graduated with attitudes quite different from those who traditionally looked down on technological learning as that of “foreign barbarians” (Liu 2006, p. 12).

14.4 Special Features of the Fuzhou Shipping Educational Program

The Fuzhou Shipping School and shipyard were established at the same time, thus integrating teaching and practice. Teachers, engineers, and students all participated in factory labor and production tasks. The design majors painted structures, and during the 3 years of learning, eight factory internships had to be completed so that students became familiar with the actual details of tools, power turbines, and more, preparing them for executing construction drawings and managing operations.

The integration of school and factory meant that each major could arrange a series of specialized internships. For example, the machine manufacturing specialty had a steam engine construction practicum, and the shipbuilding specialty had a hull construction practicum, with hours of manual labor required in each lesson. There was also an 8-month factory internship for the 3-year study of design. For the ship assemble and repair major, students were required to complete an engine assembly on shore and then practice machine installation in a newly constructed ship. Students in the navigation specialty first studied basic lessons and sailing knowledge for 5 years, and then over 2 or more years acquired practical skills of navigation, naval warfare, artillery use, and command necessary to captain a navy vessel.

There are obvious advantages to the integration of school and factory. First, it better reflects the education necessary for productive labor in the profession. Instructors can double up as teachers and engineers for a class and in the factory. Students were apprentices, not only learning in class, but also participating in production work. Other schools of practical arts—including Christian missionary work-study programs, which exercised their own influence on emerging educational systems in China—had students work as both trainees and apprentices in similar "dual systems" of integrated theory and hands-on experience, to create a coordinated experience in management, design, and construction. Students graduated ready to move directly into professional (Shen and Jin 2007, pp. 68–71).

The Fuzhou Shipping School also relied, at least initially, on foreign experts. Hiring foreigners to teach students was thought to be the best way to change the closed-door policy of feudal society in China and to acquire advanced technology from the West. Indeed, foreign experts were an important factor in its success. During its start-up period, all Fuzhou Shipping School teachers and assistants were from outside China. Records indicate that during its first year Fuzhou employed a total of 42 foreign teachers (25 French, 9 British, and 2 Singaporean).

In 1877, the Shipping School sent 30 students of the first class of students in each of the two front and back units to learn manufacturing in France and navigation in Great Britain. In 1881, ten students of the second class were sent, and the third session was sent in 1886. Prior to the outbreak of the First Sino-Japanese War in 1894, Fuzhou had sent a total of 64 students from the first three classes to study in France and Britain. Previously, the Qing Dynasty had the practice of sending young students to study abroad in the United States, but only to develop "reserve talents for the country" without a specific purpose other than learning about Western culture.

The Shipping School, however, used its study abroad program to send outstanding students to acquire specific technical skills and engineering knowledge.

Guidelines for the study abroad program and teaching plans were formulated by the French naval officer Prosper Giquel, whom the school had hired as a foreign administrator, along with Li Fengbao, the Chinese administrator. Both administrators supervised the foreign study students. Additionally, unlike the students sent to America, those from Fuzhou were mostly adults who already had a level of technical training. In their 3 years abroad, the first 4 months to visit and investigate various regions and was probationary, they expected to further their theoretical knowledge and practical skills. Students were examined once every 3 months with a final exam taking place at the end of their 3 years foreign study.

14.5 Influence of the Fuzhou Shipping School on Engineering Education

Over time graduates of the Fuzhou Shipping School became the principals, deans, and teachers of other naval academies. Examples include Yan Fu, who served as the dean, vice principal, and principal of the Tianjin Naval Academy; Wei Han, who became the principal of the Huangpu Naval Academy; Jiang Chaoying, the dean, dispatcher, and principal of the Jiangnan Naval Academy; Sa Zhenbing, who established the Yantai Naval School and served as principal of the Wusong Merchant Marine School.

The curriculum and distinctive features of the Fuzhou Shipping School were thus emulated by many other higher educational institutions. For instance, the *Shi Xue Guan* (Western Studies) program in Guangdong stated clearly in its constitution that it was set up based on the Fuzhou Shipping School model, while taking into consideration the specific situation in Guangdong Province.

In like manner, Fuzhou influenced the Fuzhou Telegraph College, Tianjin Telegraph College, Shanghai Telegraph College, Tianjin Medical School, Tianjin Shipbuilding College, Guangdong Shipbuilding and Army College, Jiangnan Shipbuilding College, and Tianjin Arms Equipment College. New colleges in different areas not only increased their teaching of fundamental and applied sciences, but also broke with the traditional teaching model by combining theory and practice. As a result students not only acquired a better knowledge of theory but also acquired practical skills.

Along with the influence of its educational model, Fuzhou Shipping School students themselves, as previously suggested, had impacts of their own. Between its opening in 1867 and closure in 1907, Fuzhou had 629 graduates who contributed to the modernization of Chinese industry. This cohort became the earliest engineering, technical, and technical management specialists in modern China. Many great names of modern Chinese history such as Yan Fu, Deng Shichang, Zhan Tianyou, and Sa Zhenbing were all Fuzhou alumni. More specific examples of Fuzhou influence include the following:

- Education of the first cohort of marine engineers.
- Outstanding early graduates in manufacturing such as Wang Qiaonian, Wei Han, Chen Zhaoao, and Zheng Qinglian.
- For the *Yixin*, the first ship designed and constructed in China, the hull design came from graduates Wu Dezhang and colleagues, with the turbine and tank designs by Wang Qiaonian.
- In 1879 Wei Han, director of the Shipping School Manufacturing Engineering Office, and his colleagues Chen Zhaoming and Zheng Qinglian, assumed responsibility for the whole Office of Foreign Experts and became the technical advisers center for the Shipbuilding Bureau.
- In 1883, the *Kaiji,* the first independently designed and constructed cruiser, was designed and built by the Fuzhou Shipbuilding Bureau.
- From 1869 to 1905, records indicate that as many as 44 naval and merchant marine vessels of different classes were designed and constructed by Fuzhou graduates.

Going beyond naval engineering, Zhan Tianyou, a member of Fuzhou's eighth graduating class, was an outstanding railway engineer. From 1905 to 1909, he presided over design and construction of the Beijing-Zhangjiakou Railway, the first designed and built by Chinese. This was an arduous project, difficult even for the foreign experts at that time, and was a great achievement for China. Wei Han (mentioned above) participated in building the Guangzhou- Kowloon Railway, and later served as directed the Henan Xuchang railway construction project.

Another Fuzhou graduate, Gao Lu, prepared the "Changchun Almanac", built China's first astronomical observatory, formally determined the latitude and longitude of Beijing, educated a number of meteorological measurement experts, and is regarded as the founder of modern astronomy in China. Other graduates participated in the establishment of China's first aircraft manufacturing factory, and succeeded in manufacturing the first 150 horsepower airplane. They later independently designed and manufactured 15 aircraft, making a significant contribution to Chinese aviation industry development.

Graduates of Fuzhou made significant contributions to almost all military and civilian industrial sectors, from metallurgy and mining to machinery, aviation, telegraphy, and weapons. As leading members of a technical elite in the late Qing Dynasty, their importance to Chinese industrialization can scarcely be overestimated. Their status and influence went beyond that of the Guangdong Huangpu Military Academy, which was founded in 1924 by Sun Yat-sen and whose graduates are often credited with modernizing leadership.

Finally, the Fuzhou Shipping School nurtured the talents of a number of figures who made remarkable contributions to East-West cultural exchanges of a more general character. Yan Fu, a graduate of the first class, systematically introduced and disseminatee capitalist culture and scientific knowledge in China. He translated eight Western classics, of which T.H. Huxley's *Evolution and Ethics* (1893) had the greatest influence. The materialist theory of evolution, natural selection, and survival of the fittest argued by "Darwin's bulldog" promoted an Enlightenment ideology that inspired a generation of patriots to work to save China from foreign subjugation. As a modernizing leader, Yan Fu influenced many other Chinese intellectuals, from Kang Youwei and Cai Yuanpei to Mao Zedong. Wang Shouchang, a graduate of the third class, co-translated with Lin Shu the sensational French drama "Camille." Chen Jitong, another graduate, was the first translator into French of two Qing Dynasty classics: Cao Xueqin's *Dream of the Red Chamber* and Pu Songling's *Strange Tales from a Chinse Studio*.

14.6 Evaluation of Engineering Education in the Fuzhou Shipbuilding School

There are different perspectives on the origin of Chinese engineering education. Wang Lieying (2004) regards the Fuzhou Shipping School as the beginning of modern Chinese higher education in engineering, while Hong Zhao and Yong Jin think Peiyang University was the start. Qian Wei (2002) suggests it arose from multiple schools established by the Westernization Group of the late Qing Dynasty. In our view, Peiyang (now Tianjin) University, founded in 1895 in the wake of the First Sino-Japanese War, is the best candidate.

Chinese engineering education can be divided into two types: academic and non-academic. Academic engineering education sees engineering as based in engineering knowledge as a special, explicit form of knowledge. It emphasizes the scientific basis of engineering practice and focuses on education in scientific theory and technical knowledge. Non- academic engineering education views engineering knowledge as tacit knowledge, emphasizes engineering practice, and focuses on the student acquisition of specialized skills. For a long time, influenced by the Western engineering education principles, Chinese engineering education attached more importance to theory than practice, which limited the practical ability in Chinese engineers. Prior to the modern period, however, Chinese engineering education had a strongly practical orientation, an orientation that was picked up and developed the Fuzhou Shipping School.

There is, of course, a problem here with the meaning of the term "engineering." As Wang Nan (2013) has pointed out, the Chinese 工程 *gong cheng* does mean exactly the same thing as the English term "engineering." Li Bocong (2002) has proposed that Chinese engineering needs to be understood in quite different terms than is engineering in the West. Carl Mitcham (2014) has further argued that there are serious questions in the West about whether the English term "engineering" is properly applied to the building of such premodern structures as the pyramids or Great Wall; in the West, the traditional term for building was not "engineering" but "architecture." Compounding this semantic difficulty is the fact that "naval architecture" is the common English term for what might otherwise be taken to be engineered shipbuilding and maintenance along with the operation of naval vessels and structures. As a result, the Fuzhou Shipping School might most properly be referred to in English as the Fuzhou School of Naval Architecture. For present purposes, however, we will continue to accept the name Fuzhou Shipping School and some continuity between premodern and modern making and building—with the qualification that questions can be raised about the precise character of this continuity.

Historically, what have sometimes been called engineers of the past were skilled and experienced artisans. However, after the eighteenth century Industrial Revolution, the theories and knowledge of the natural sciences were applied widely and deeply in engineering and production, requiring the industrial production technology structure to gradually become multilayered with various teams. Not only did the artisans of the lower level need to master certain scientific and cultural knowledge, but a higher professional class above the artisan, i.e., technicians and engineers, gradually emerged. The engineering expertise team of Western industrialized countries formed a basic hierarchical structure of workers, technicians, and engineers.

In the 1960s and 1970s, Chinese industrialization was in its initial stage. Those people who strongly advocated the development of a modern machine industry and industrial education still lacked a clear understanding of the multilevel modern engineering expertise team structure. They often focused on skill training and ignored the training of engineers who are “familiar with scientific principles”. The situation was changed by the end of 1990s, with greater understanding of the nature and the characteristics of higher engineering education and the purpose of training engineers (see Shi 2004, pp. 105–106).

The development of modern engineering education has been one of the most important aspects of China’s educational and social modernization. Based on the historical logic of strengthen the army and revitalize our country, develop industry, cultivate intellectuals, enhance education, the appearance of modern engineering education in China started with transplanted ideas from the West. The incorporation of engineering into national goals and planning reflects the direct power, importance, and influence of Chinese engineering education development.

However, because the endogenous modernization of the West was from the bottom up, engineering education development in the original industrialized countries was organically influenced by the practical requirements of industrial society. Because China modernized later, engineering education was founded in conjunction with national planning and the transplant of modern Western modes, with the process inevitably creating all kinds of maladjustments in Chinese society. This maladjustment was manifested, on one hand, as isolation from traditional Chinese society and culture, resulting in conflict between culture and concept. On the other hand, it is also isolated business enterprises and the market from engineering educational development, and Chinese economic development and the process of industrialization was often in an unharmonious state.

14.7 What Happened to the Fuzhou Shipping School

Despite is importance and influence, as mentioned above in the brief history, the Fuzhou Shipping School closed down after 40 successful years. How is this to be explained?

The proximate cause of the closing of the Fuzhou Shipping School was, of course, the Xinhai Revolution of 1911. After the fall of the Qing Dynasty, the new Republic of China was not inclined to continue supporting an institution that had been closely associated with a discredited imperial government. But another factor was that engineering and technology had not yet acquired an important place in Chinese culture.

In America, engineering education, which is primarily for the purpose of creating engineering professionals, is nevertheless able to build on popular middle and high school vocational training that includes the acquisition of scientific and technical knowledge in mathematics and the sciences that emphasizes their practical application. This emphasis on practical application continues at the university level. According to higher education scholar Xie Zuzhao, "Higher engineering education is a kind of professional and technical education, one of the important tasks of which is to train students to master the basic knowledge of natural science that gives the students have the kind of knowledge that can be practically applied" (Xie and Fu 1992, p. 1). Another observer, hydrological engineer and academician Zhang Guangdou, has pointed out that "higher engineering education has two basic characteristics as a kind of technology education: On the one hand, it takes technology and science as its main subject foundation, and the application of technology as its main professional content which distinguish the scientific education; on the other hand, it takes engineering application as its main service object" (Zhang and Wang 1995, p. 29).

The nature of engineering lies in application, practice, and innovation. Engineering manifests itself as practical rationality related to contingency, purpose, trial, and error. As American philosopher Steven Goldman notes, differences between engineering and science represent in the West different cultural traditions and two understandings of rationality (Sheng and Wang 2005). Engineering rationality and scientific rationality characterize two traditions that are often mutually antagonistic. Throughout the development of Western culture, the scientific conception of rationality has dominated and engineering rationality has often been rejected as irrational. Likewise, relative to science education, engineering education has had less cultural and social respect. As a practical activity, engineering is not only a process of knowledge application, but more of a process of knowledge integration and innovation. Part of the historical process of modernization in the West involved a progressive increase in social appreciation for practical rationality, a process that had not yet begun to take hold in Chinese culture as a whole in 1912. On the whole, at that time Chinese culture strongly influenced by a Confucian tradition that functioned somewhat like theoretical science had done in the West to belittle interest in technology.

Engineering is the process of designing, building, and operating artifacts for the purpose of enhancing the human environment. Its main contents include the specification of goals, functional analysis, trade-off decision-making, and the forecasting of consequences. Engineering knowledge is task-targeted and focuses on the production of artifacts to fit needs for an intended purpose (Li 2004). As a result, unlike pure scientific knowledge, which can be obtained in the laboratory and verified by reasoning, engineering knowledge is strongly associated with action and is tested externally in a project.

In terms of educational curriculum, these features of engineering require basic and comprehensive scientific knowledge, engineering design skills, and the inclusion of humanities and social sciences adapted to engineering practice, together with practical knowledge and experience. Because of its intrinsic character engineering education will need to include explicit (scientific knowledge) and tacit (practical skill) features. Explicit engineering knowledge can be acquired through formal learning processes, whereas tacit knowledge must rely on the experience of engineering activities (Duan 2007).

As a way to suggest a more structural account of what happened to the Fuzhou Shipping School, we might appeal to a framework developed by Burton R. Clark, an American scholar of higher education In an influential study Clark (1983) undertook to compare systems of higher education in eight Western countries (supplemented with some reference to two East European and two developing countries—not including China), and proposed what he called a "triangular coordination mode" to account for institutional differences. The three key factors were the academic profession itself, the state, and the market or economy. Clark's analysis, which also privileged the power and influence of the academic profession and the level of independence it had developed from other social institutions in the West, has often been used to account for differences in higher education systems across national boundaries—and the extent to which high education across national boundaries strongly exhibits many common features.

Companion responses to Burton's work in the journal Higher Education the year after its publication nevertheless raised concerns about the adequacy of his framework for developing countries. The first review by a British academic (Mattison 1984) generally praised Burton, while the second review by an academic Singapore asked questions. In his words, "when we closely examine and analyze higher education systems in different Third World countries, we see that the basic elements … have, to a considerable extent, inhibited these Third World academic institutions from being relevant and nationally oriented" (Selvaratnam 1984, p. 738). Something of the same point was reiterated a decade later by another commentator who argued that Clark's framework could not account for the impact of specific social, economic, and cultural factors of different countries on institutional developments in higher education (Williams 1995).

While recognizing the value of Burton's framework, but in an effort to take into account some of the critic's concern, we would like to propose expanding his framework. To the three factors of academic profession, state, and market, we would add

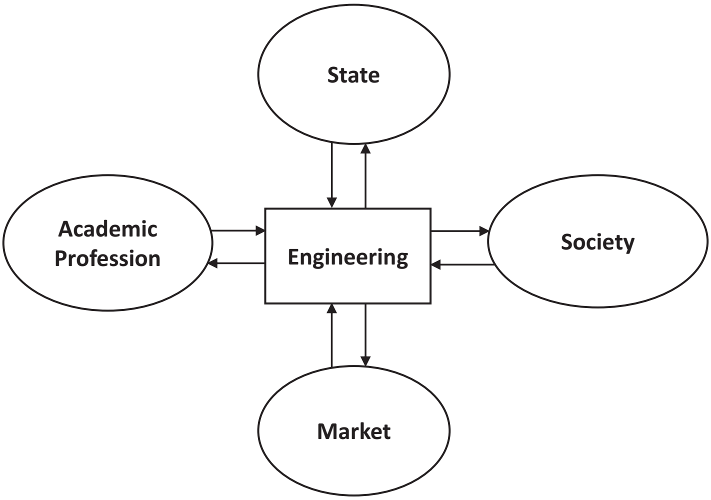

Fig. 14.1 Proposed quaternary interpretative framework combining state, society, knowledge, and market

society as factors properly influencing especially engineering higher education (Fig. 14.1).

The changing strengths of these four factors in relation to each other provide a useful framework for interpreting the development of engineering education in China. As a result of state or political concerns, early Chinese engineering education was highly influenced by models from Germany and Japan. The Qing Dynasty state, in response to its defeats in the Opium Wars and the First Sino-Japanese War, viewed engineering education as a means to protect the state from foreign enemies. As the historian of Chinese education Shu Xincheng as observed, the reason for implementing a new school system at that time was not the needs of the country or its people, nor did it grow from an awareness of scholars and educators. It was simply that Qing Dynasty rulers thought the power of other countries was based in their specific educational systems and that therefore the Chinese needed to imitate them in order to survive. Although Shu was referring to the educational system as a whole, it applies as well to engineering education

Over time, however, policy making elites gradually became aware of the need to take into account academic, market, and social factors. The subsequent development of engineering education in China—a critical history of which remains to be written—could well be analyzed in terms of the inclusion of these other factors. Indeed, sometimes other factors also became dominant in ways that distorted engineering education, as revealed by the study of education at Tsinghua University during the early years of the People's Republic of China (Andreas 2009).

From its beginnings, Chinese engineering education had to learn properly to moderate state factors and to take into account academic and market forces, but in the process has been heavily influenced by various societal constraints, from traditional cultural values to Marxist revolutionary ideals and technocratic interests. Slowly science and technology have had to be integrated into primary and secondary education throughout the country so that the public as a whole can benefit and influence social development. This process has been a special concern of the Chinese Association for Science and Technology, which has a general mandate to promote scientific and technological literacy. With regard to the market, unlike in the West, Chinese engineering aspires to serve the people in broader ways than simply meeting market (enterprise) needs. The task of integrating these factors into professional engineering will be a continuing responsibility of engineering education in China.

14.8 Apology

An earlier, incomplete version of this article (neither refereed nor edited, and with many errors) was unfortunately published under the name of the first author only as "The Origin of Chinese Modern Engineering Education: Fuzhou Shipping School's Engineering Education at Late Qing Dynasty," in the faux scholarly *Philosophy Study*, 4(4) (April 2014), pp. 302–314. The senior author regrets his mistake in allowing that earlier publication.

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Chapter 15
The Earliest Western-Trained Engineers in China's Iron and Steel Industry

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Abstract Early industrialization of iron and steel production in China began with establishment of the Hanyang Iron Works at the end of the nineteenth century, which in the early twentieth century became the Hanyehping Coal and Iron Limited Company. In order to develop its own expertise, the Hanyehping Company sent some ten Chinese students to Western countries to study metallurgy. These students would later become the first generation of Chinese iron and steel engineers and play a crucial role in the modernization of iron and steel technologies and industrialization in China. This article focuses on some foreign study experiences of these engineers and their subsequent working lives in China, from 1894 to 1925, thus providing insight into how the modern Chinese iron and steel industry was established and how the earliest efforts to transplant Western metallurgy technology in China were made.

15.1 Introduction

Although establishment of the Qingxi Ironworks 清溪铁厂 in 1887 signaled the start of modern iron and steel industrialization in China, this enterprise ceased operation only 2 years later. At almost the same time, the Viceroy of Hu Guang, Zhang Zhidong 张之洞 began construction of Hanyang Iron Works 汉阳铁 厂 on the south bank the Han River. It commenced production in 1894, and enabled Zhang to

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realize his dream of using China’s own resources to build the Beijng-Hankow Railway 京汉铁路. In order to solve the financial problem of the ironworks, Zhang entrusted management of Hanyang Iron Works to Sheng Xuanhuai 盛宣怀, who was on the staff of the Beiyang Commerce Minister, Li Hongzhang 李鸿章.

Later, the government run ironworks was changed into an enterprise operated by merchants and supervised by government officials. In 1908, in order to raise funds for a large expansion plan of the Hanyang Ironworks, the Dayeh iron mine 大冶铁矿 and the Pingxiang colliery 萍乡煤矿 were merged and the name changed to the Hanyehping Coal and Iron Limited Company 汉冶萍煤铁有限责任公司, making it the largest Iron and steel enterprise in the Far East. After its heyday around 1910, the Hanyehping Company ceased production in 1925.

The Hanyehping Company was the epitome of iron and steel industrialization during the early transfer of modern Western iron and steel technology into China. During the period of the construction and development of the iron works, students were sent by the Hanyehping Company to universities in Europe and America to study metallurgical engineering and earn bachelor and in some cases master degrees. These students became the first generation of modern Chinese iron and steel engineers and were a practical conduit for technological transfer from the West to early modern China. Their experiences are an important part of the history of Chinese modern metallurgical engineering.

The Hanyehping Company has long been popular in the history of modern China, serving as a typical case for research on economic development and industrialization. Most researchers have used its ultimate failure to elucidate what they see as the main obstacles to Chinese industrialization, chief among them the impact of traditional Confucian culture (Feuerwerker 1995). We argue, however, that those participating in a historical process cannot choose their social culture, so in our research, traditional social culture and its impact, disadvantageous or otherwise, should just be looked upon as preconditions. Therefore, we focus on the processes that went on under such preconditions: in this case, the behavior and role of the earliest Chinese engineers in iron and steel industrialization. What follows is a survey of the experiences of the early generation of the iron and steel engineers during the time of Hanyehping Company from 1894 to 1925, through which the characters participating in the evolution of modern iron and steel engineering and industrialization can be presented.

15.2 Foreign Engineers at Hanyang-Hanyehping in the Initial Stage

Owing to the absence of its own Chinese technicians, foreign engineers initially directed all technical activities at the Hanyehping Company, including:

- Designing and building the Hanyang Iron Works
- Exploring and opening the Dayeh iron mine
- Investigating and constructing the Pingxiang Colliery
- Directing operations at all three sites

Table 15.1 The technical directors and engineers in Hanyang Ironworks (1890–1912)

Technical Director	Nationality	Period	Engineers and Technicians
Henry Hobson	UK	1890–June 1892	British
Emile Braive	Belgium	1892–1896	Belgian and Luxemburger
Gustav Toppe	Germany	1896–1897	Belgian, Luxemburger, German
Kennedy	America	1897–1898	Belgian, Luxemburger, German
Vacant		1898–1905	Belgian
Eugene Ruppert	Luxemburg	1905–1912	Belgian, Luxemburger, German
Woo Zung Tse Kim	China	1912-	Belgian, Luxemburger, German; Chinese after 1914

Source: Ruppert (n.d.)

These technical activities enabled the company to produce rail and other iron and steel outputs during a time when the Chinese did not yet posses their own modern technological capabilities.

From 1890 to 1912, the Hanyang Ironworks hired six foreign technical directors as well as others to carry out and supervise technical work in every aspect of production (Table 15.1). The foreign employees at Hanyang Ironworks totaled 35 from 1895 to 1897.

As a result of frequent conflicts between the foreign technical directors and their Chinese colleagues, as well as a certain amount of diplomatic opportunism, the Hanyang Iron Works changed its technical director frequently during the years 1890–1905. The first technical director, Henry Hobson, came from the UK, the location of the Hanyang Iron Works' equipment supplier. The second director, Emile Braive, was a Belgian engineer. Under his direction, the second batch of equipment in Hanyang Ironworks came from the Cockrell Works in Belgium. Hanyang Ironworks also hired some engineers and technicians recommended by the Cockrell Works. After expiration of the contract with Braive, Zhang Zhidong in 1896 commissioned the Krupp Company in Germany to find a third technical director, Gustav Toppe. Toppe left soon after in 1897 because of serious conflicts with his Chinese colleagues. However, the appointment of the fourth director, Kennedy, did not improve the difficult relationship between foreign directors and the Chinese managers. Meanwhile, new conflicts arose between the American director and Belgian technicians. In 1905, Hanyang Iron Works accepted a suggestion from the Belgian Embassy in Hankow to hire a Belgian technical director (Chen 1984, p. 833). Eugene Ruppert, who was once an engineer at the blast furnace plant at Hanyang Iron Works, became the fifth technical director.

Ruppert's work was appreciated by his Chinese colleagues and the conflicts that had troubled Hanyang Iron Works for many years were finally resolved. Such frequent personnel changes came at a high cost, both in monetary terms and morale, and encouraged directors to make a decision to have Chinese engineers trained overseas.

During this period, however, China had an especially fraught relationship with the West, as indicated by the anti-foreign and anti-Christian 义和团运动 Yihequan Movement (Boxer Uprising), which occurred between 1899 and 1902. The response was a Russian invasion in the north and a British, French, American, and German invasion of Tianjin and Beijing, with the international expeditionary force committing numerous atrocities. The mining engineer (and future U.S. President) Herbert Hoover, who in 1899 had been sent from Australia to China by a London mining company as a mining engineer, and had played an active role in the case of the alternation of Kaiping Colliery's stockholders' rights, was trapped for a short period in Tianjin. China was clearly looking for ways to resist multiple forms of Western aggression.

15.3 Training Chinese Engineers for Hanyehping: Beginning with Wu Jiane

To this end, the Hanyehping Company sent ten Chinese students to study iron and steel engineering or mining at universities in Europe and America (Table 15.2).

Wu Jian was the first student to be sent abroad, and was also the first to study for and earn a degree in iron and steel engineering. He was one of the initial graduates of St. John's College in Shanghai, where he then studied and taught for 13 years (Student Publication Committee 1929, p. 16). Before going to the UK, Wu Jian was a teacher at the Nanyang Public School, which was founded by Sheng Xuanhuai,

Table 15.2 Chinese students sent abroad to study by the Hanyehping Company

Name	Place of study	Post held in Hanyehping
Wu Jian (吴健)	1902–1908, University of Sheffield, UK	Director, Hanyang Iron works and Dayeh Iron Works
Lu Chengzhang (卢成章)	1907–1911, University of Sheffield, UK	Director, Steel Smelting Plant, Hanyang Iron Works
Guo Chengen (郭成恩)	1910–1915, University of Sheffield, UK	Director, Machine Department, Hanyang Iron Works, Assistant director, Dayeh Iron Works
Huang Xigeng (黄锡赓)	1910–1913, Lehigh University, USA	Manager, Dayeh Projet Mining Director, Pingxiang Colliery Director, Pinxiang Colliery
Yang Zhuo (杨卓)	1911–1914, Lehigh University, USA	Assistant director, Steel Smelting Plant, Hanyang Iron Works
Chen Hongjing (陈宏经)	1911–1914, USA	Engineer, Rolling Plant, Hanyang Iron works
Zhu Fuyi (朱福仪)	1913–1915, USA	Director, Department of Machine and Electric, Hanyang Iron Works
Jin Yueyou (金岳祐)	1911–1915, Germany	Director, Department of Coking
Zhao Changdie (赵昌迭)	1918–1922, Columbia University, USA	Engineer, Iron Smelting Plant, Hanyang Iron Works
Cheng Wenxi (程文熙)	1913–1918, Belgium	

the director of the Hanyehping Company in 1896, for the purpose of learning Western knowledge. To gain this knowledge, some outstanding students in Nanyang Public School and Beiyang School were chosen by Sheng Xuanhuai to be sent to study at universities in Europe and America. The funding sources for these students varied, with some supporting themselves, and some supported by a public foundation. Among these students, Wu Jian was the only one supported by the Hanyang Iron Works (Sheng 1963, p. 242).

In October 1902, Wu Jian signed a contract with the Hanyang Iron Works that stipulated the conditions of his study abroad and work after his return. It included the subject of study as iron and steel engineering, and the salary for the first 2 years after returning to China as 200 *tael* per month. This contract became a model that established the standard for later students sent abroad.

Wu arrived in the UK in 1903. According to the archives of the University of Sheffield, after a brief time studying at the City and Guilds Technical College in London, he enrolled at Sheffield. He was a pioneer from the point of view of the university, since he was not only their first international student, but also one of the first students to earn both bachelor and master degrees in metallurgical engineering. Wu Jian's archive card reads: "Permitted, upon payment of the fees prescribed for degrees, to enjoy all privileges as graduate pending the holding of the first congregation."

While in Sheffield Wu also obtained an Associateship in Iron and Steel Metallurgy (AISM), the standard for which was kept very high by the technical school. It is said that despite the large number of students who attended each year after 1890 (averaging between 500 and 600), only 20 obtained the Associateship in the years up to and including 1897 (Chapman 1955, pp. 79–80). We do not know the number of students who obtained the Associateship in 1907, but what is certain is that, since he earned the AISM and two degrees, Wu obtained a thorough education in the subject of iron and steel metallurgy.

Wu returned to the Hanyang Iron works at the end of 1908 to begin his engineering emprolyment. This was the same year that the Hanyang Iron Works, Dayeh iron mine, and Pingxiang colliery merged into the Hanyehping Coal and Iron United Company.

15.4 Other Hanyehping Study Abroad Students

The year 1908 was a promising one for the Hanyehping Company. The large-scale reconstruction of the Hanyang Iron Works paid off when two new Martin steel furnaces, which could make rail of very high quality, went into operation. The construction of the No. 3 blast furnace took place as well. Additionally, the capital construction of the Pingxiang Colliery was finished and solved the Hanyehping Company predicament of securing a sufficient supply of iron ore and coal. Orders were flowing in, and the company even realized a profit that year.

Such good conditions allowed the company leaders to pay more attention to the training of Chinese technicians, with 1910, 1911, and 1913 the peak periods for sending students abroad. During this time, eight students went abroad: two more to the University of Sheffield, one to Belgium, one to Germany, and four to the United States, two of whom studied at Lehigh University, which was well respected for its mining and metallurgy engineering program. The remaining two students went to Belgium and Germany. A final Chinese student was sent by the company to Columbia University 1918. Just as with Wu Jian, all the students studied subjects that were crucial to the production requirements of the company, such as steel engineering, coal mining, and mechanical engineering. Most obtained bachelor or master degrees.

It is well known that prior to the Hanyehping Company, another Yangwu enterprise, the Fuzhou Shipyard 福州船政局, had also sent four groups of students to receive training abroad. However, the background of these students, as well as the selection process and supervision of them while abroad, was quite different than those from Hanyehping.

First, a notable characteristic linking all ten Hanyehping's students was their prestigious backgrounds. Lu Chengzhang's father, 卢洪昶 Lu Hongchang, was a famous businessman in Ningbo, and held the post of Director of the Office of Transportation and Sales at the Pingxiang Colliery. Guo Chengen grew up in a wealthy Cantonese family doing business in Shanghai. Jin Yueyou's father had followed Zhang Zhidong for many years, taking part in the "foreign affairs movement" (yangwu yundong 洋务运动) and holding posts as Director of the Hunan Railway Company and the Mohe Gold Mining Bureau in Heilongjiang. Yang Zhuo was the son of a famous painter, 杨逸 Yang Yi, who wrote 海上墨林 *Hai shang mo lin* (Ink forest on the sea). Coming from such well-off backgrounds, all these students had obtained good educations in the best modern schools in China—such as the Nanyang Public School, Shanghai, St John's College, Shanghai, or the Beiyang School, Tianjing—before going abroad. Thus they did not choose to study iron and steel engineering out of necessity but by choice. The background of the students sent by the Fuzhou Shipyard, however, was quite different. Most came from ordinary families, some even needing to use their stipend to support a family (Chen and Tian 1991, pp. 258–272).

Second, the Hanyehping Company selected its students through recommendations by acquaintances, with the families of most students having some kind of relationship with the company. For example, the fathers of Lu Chenzhang and Zhao Changdie were staff at the Hayehping Company. Managers of the company gave recommendations for Wu Jian and Jin Yueyou. Recommendations also meant the students could get company funding for their studies.

A third difference between the Hanyehping Company and the Fuzhou Shipyard was the way students were supervised. The Hanyehping Company provided more freedom to its students on the arrangements of their study, with the details of the study abroad made completely by students themselves. There was no limit on the number of years of their study. However, the Fuzhou Shipyard students were under strict supervision, with a schedule and directions for every aspect of life abroad, from training courses, accommodations, to clothing. Some supervisors were even sent by the shipyard to accompany the students (Chen and Tian 1991, pp. 263–265). The different supervision methods represented the different purposes of the two programs. The Fuzhou Shipyard sent students abroad only to allow Chinese artisans to acquire technical abilities to operate equipment at the shipyard. The Hanyehping Company, by contrast, supported students in order for them to obtain a systematic education and degrees in metallurgy or mining engineering. Because of this, Hanyehping Company students were able do more for the overall development of Chinese metallurgy engineering technology and its industrialization.

The differences between the students of the Hanyehping Company and the Fuzhou Shipyard also highlight some of the changes that Chinese society was undergoing with the process of industrialization. Members of the elite class of traditional China, the rich gentry and intelligentsia, were becoming more willing to send their sons to study such subjects as metallurgy or mining engineering, enabling a society more compatible with industrialization to emerge, and creating a new professional group: industrial engineers.

15.5 Chinese Engineers Replace Foreigners

In late 1908, Wu Jian, the first Chinese engineer at the Hanyang Iron Works, returned to China and began his career working under technical director Ruppert. The main tasks of the iron works at that time were to make enough rails to meet its orders, and to build the No. 3 blast furnace, which would greatly increase iron output. Such a situation gave Wu a good opportunity to practice his new skills. The No. 3 blast furnace went into operation in 1910. Meanwhile, the company had achieved its highest profits. All seemed to be going well.

The outbreak of the 1911 Xinhai Revolution 辛亥革命, however, proved to be bad news for the Hanyang Iron Works. The factory was forced to cease production and all foreigners went to Shanghai, with most leaving China not long after. Ruppert was among the few who decided to wait to see how things would develop. In 1912, pressured by a loan contract between Hanyehping and a bank in Japan, the Hanyang Iron Works needed to get back into production as soon as possible. Wu Jian was appointed as technical director and took charge of the repair to the furnaces.

This was a special period for the Hanyang Iron Works, with its first Chinese technical director leading Chinese students recently returning from abroad in the totally new task of repairing furnaces and bringing them back into full operation. At the same time, Ruppert remained at the factory providing help to his successor. As the repairs approached completion, Ruppert was appointed advisor in Europe by the Hanyehping Company, representing it across the whole of Europe until 1923. The No. 1 and No. 2 blast furnaces resumed operation in November 1912, and from then on, the technical activities of the plant were led by a Chinese director Wu Jian. The other Chinese students returned to China one by one around 1914, and at the same time the company hired more Chinese students who had also studied abroad (Table 15.3).

Table 15.3 Other Chinese students hired by the Hanyehping Company c. 1914

Name	Place of study	Post held in Hanyehping
Yan Enyu (严恩棫)	1906–1912, Mining and Metallurgy engineering, the Empire University of Kyoto, Japan	Director, Plast Furnace Plant, Hanyang Iron Works
Li Minghe (李鸣和)	1909-?, Chemical engineering, Metallurgy engineering, the University of Wisconsin	Engineer, Steel Melting Plant, Hanyang Iron Works
Wang Chongyou (王宠佑)	1895–1899, Department of Mining, Beiyang University, China; 1901–1902, Mining Engineering, University of California, Berkeley, USA; 1902–1903, Columbia University, USA, Master Degree of Mining	Engineer, Director, Dayeh Iron Works
Cheng Yizao (程义藻)	1909-? Mechanical Engineering, Cornell University, USA	Engineer, Steel Smelting Plant, Hanyang Iron Works
Cheng Yifa (程义法)	1909–1914 Mining Engineering, Colorado School of Mines, USA	Engineer, Pingxiang Colliery
Huang Jintao (黄金涛)	Metallurgy, Columbia University, USA. Master Degree 1915	Engineer, Blast Furnace Plant, Hanyang Iron works
Wang Guanying (王观英)	USA	Director, De Dao Wan Mining District, Dayeh Iron Mine
Tong Xianshu (仝咸澍)	France, Electrical Engineering	Engineer, Hanyang Iron Works
Yang Huayan (杨华燕)	1907–1908, Civil Engineering, Yale University, USA, Obtained Bachelor Degree; 1909–1910, Mining Engineering, Lehigh University, USA, Bachelor Degree; 1910–1911, Mining Engineering, Columbia University, USA, Master Degree	Engineer, Dayeh Iron Mine

Some details about one of these students, Cheng Yifa, provide further context and background for this cohort. During his studies at the Colorado School of Mines, Cheng Yifa wrote a short essay in the *Colorado School of Mines Magazine* on "The Far Eastern Problem." In his essay he expressed a Chinese study abroad student's concern about the future of China (Chen Yefah 1911). (This essay is included here in an appendix).

It is notable that the first year salary of the Chinese study abroad students was more than that of those whose study abroad was not supported by Hanyehping Company, reflecting its trust in its own students (Hubei Archives 1992, pp. 436). In fact, because of the limited number of the company's own students, their abilities were the main standard by which they were placed into jobs. Although there were still some foreigners in the company, more and more Chinese who had been students worked there, constituting the core technical personnel. In 1918, the Chinese technicians of the Hanyehping Company accounted for 90% of the total, while only four foreign technicians remained.

15.6 The Role of the Chinese Engineers

As the first group of Chinese engineers in the Hanyehping Company, returning students played essential roles not only in the technical activities of the company, but also in the evolution of Chinese modern iron and steel engineering. For example, it was these students who got the Hanyang Iron Works functioning again after the 1911 revolution. The main task in this regard involved building the No. 3 and No. 4 blast furnaces and constructing seven new Martin steel furnaces of 30 tons each. The reconstruction was directed by Eugene Ruppert before the revolution, but afterward was then taken over by Wu Jian and the Chinese engineers. The Chinese engineers not only completed repair of the old furnaces, but started to build the No. 4 blast furnace and No. 7 Martin steel furnace. Though the designer of the new blast furnace was Ruppert, a number of design adjustments were made by Wu Jian during the construction process, and design and construction of the No. 4 blast furnace was carried out completely by this earliest cohort of Chinese engineers, going into operation on June 12th, 1915 (Hubei Archives 1992, pp. 499).

In the meantime, some Chinese engineers had obtained important posts in various company plants. Besides Wu Jian, who was appointed director of the Hanyang Iron Works soon after the repair work was finished in 1912 (Hubei Archives 1992, p. 434), the company appointed Wang Chongyou as director of the Dayeh Iron Mine in 1914 (Hubei Archives 1992, p. 446), and Huang Xigeng, one of the students sent abroad by the Hanyehping Company, as technical director of the Pingxiang Colliery, taking charge of coal mining (Chen 2004, p. 833). These appointments meant that the daily management in the Hanyehping Company was taken over by men very different to their predecessors, presenting a new class of managers in the iron and steel enterprise who had mastered modern metallurgy engineering knowledge.

However, there were many disagreements surrounding these new managers. In 1905, Wang Chongyou and another manager Wang Guanying were criticized by a colleague in these terms:

> The theoretical knowledge and the English level of these two gentlemen is high enough to be a teacher in a university. As to being a manager of a mine, however, they lack both the experience and the general knowledge required, and are just like the old-style young scholars (举人 *juren*), who had their minds full of poems, and who once they became an official did whatever they like until criticisms welled up. (Hubei Archives 1992, pp. 453–454)

This was a typical opinion about these young engineers and managers at that time. Most were able to find their feet after a period of friction, but Wang Chongyou chose to leave the company; his later successes proving that the company lost a person of considerable ability. Furthermore, although some engineers became managers, none rose to the top leadership of the Hanyehping Company; Sheng Xuanhuai and his close relatives and friends kept a firm monopoly on these positions of power for the entire period after 1896.

As the first generation of Western-trained metallurgical engineers, these students were key figures in the process of transferring Western iron and steel technology into early modern China. Strictly speaking, the Hanyehping Company was not the starting point for the transfer of this technology into China; before the construction of Hanyang Iron Works, information came through translating foreign technical books. For example, in the late Ming Dynasty, Georgius Agricola's monograph *De re metallica* was translated into Chinese by the missionary Johann Adam Schall von Bell and his Chinese colleagues Yang Zihua and Huang Hongxian. Though the knowledge in this book cannot be considered as modern metallurgy knowledge, it was still important. The earliest modern metallurgical engineering books were translated and published by the Jiang Nan Arsenal during 1870s. These translations included two volumes by American metallurgists James Dwight Dana's *Manual of Mineralogy* (from 1848) and Frederick Overman's *The Moulder's and Founder's Pocket Guide* (from 1851) along with Scottish civil engineer and shipbuilder William Fairbairn's *Iron: Its History, Properties, and Processes of Manufacture* (from 1861) (Wang 2003).

If the translation of Western books can be regarded as the first step in the process of transferring Western metallurgical technology, then the second was construction of modern iron and steel plants such as the Hanyehping Company and the importation of equipment from the West. Training the Chinese engineers can be regarded as a third step of this process. From the perspective of the evolution of modern iron and steel engineering in China, these Chinese engineers did pioneering work that should be remembered.

Lu Chengzhang, one of the Hanyehping foreign study students, wrote the first professional book in Chinese describing the manufacturing principles of rail making in detail. His 钢轨制造法 *Ganggui zhizao fa* [Methods of rail manufacture] was published by the Office for Scientific Instruments 科学仪器馆 (*Kexue yiqiguan*) and printed by 商务印书馆 Shangwu Yinshuguan in 1909. This book was based on study notes taken at the University of Sheffield and introduced the principles and methods of rail making to China.

Over 10 or more years of practice at the Hanyehping Company Chinese engineers also improved their abilities in furnace construction. The No.1 and No.2 blast furnaces had been built by foreigners, but it was young Chinese engineers who completed construction of the No. 3 furnace and built the No. 4 furnace. Their experiences enabled some to become well-known experts in the area of iron and steel making in China. Wu Jian and Yan Enyu, for instance, continued to make significant contributions to the development of China's iron and steel industry after the collapse of Hanyehping, especially during the War Against Japanese Aggression (Second World War), when China needed to construct iron and steel plants in remote areas of western China that remained under control of the Chinese government.

Prospecting for mineral resources was another important area where the earliest Chinese engineers made a contribution. New mining regulations promulgated by the government in 1914 permitted foreigners to invest in mining enterprises in China, stimulating prospecting by foreign companies.

In order to protect its own interests, the Hanyehping Company decided to send its Chinese engineers on pioneering searches for its own mineral resources (Table 15.4). It is notable that this is the same year that Ding Wenjiang 丁文江 carried out his survey in Shanxi Province, while a large-scale investigation was undertaken by the Geological Survey of China 地质调查所 after 1915 (Editorial Board 2001, p. 27). The difference between these investigations was that the Hanyehping

Table 15.4 The prospecting activities for mineral resources carried out by Chinese Engineers of the Hanyehping Company, 1913–1919

Prospector	Time of prospecting	Place of prospecting
Huang Xigeng (黄锡赓)	September 1913	Dayeh Iron Mine
	November 1913	Yangtze River Basin (Jiujiang, Anhui, Xuzhou)
Wen Wuzi, Wei Yunji (温务滋,魏允济)	December 1913–January 1914	Henzhou, Hunan; Youxian, Hunan; Changlai, Hunan
Xu Yuanying (徐元英)	December 1913	Youxian, Hunan; Pingxiang, Jiangxi; Ningxiang, Hunan
Miu Fusheng (缪黼升)	October 1917	Xinchang Colliery, Taihuxian, Anhui
	September–November, 1917	Dangtu Iron Mine, Anhui
Huang Xigeng (黄锡赓)	November 1917	Jinxian Colliery
Miu Fusheng (缪黼升)		Liuhe, Jiangshu to Jiujiang, Jiangxi, Dangtu Iron Mine, Anhui
Wang Guanying (王观英)	December 1917–January 1918	Wuhu Iron Mine, Anhui; Fanchangxian Iron Mine, Anhui; Jingxian Colliery, Anhui Taipingfu Iron Mine, Anhui
Yang Huayan, Zhou Kaiji (杨华燕, 周开基)	April 1918	Wuhu, Anhui
Miu Fusheng (缪黼升)	July 1918	Changxing Iron Mine, Zhejiang
	September–October 1918	Ciyao Colliery, Shandong
Shen Yuanru (沈渊儒)	April 1919	Wenzhou, Zhejiang

Company kept its results confidential, while the latter published its results. For this reason, the investigation carried out by the Geological Survey of China is well known by historians as China's first large-scale mining survey, while that by the Hanyehping engineers is not.

15.7 Conclusion

The general theory in the history of technology is that it is not likely that a country or region will be able completely to alter its social situation without importing technology from elsewhere. There needs to be a group of participants who master the technology and also find ways to operate within their existing situation, and then work to make the technology take root. In the process of transferring Western iron and steel technology into early modern China, it was the Chinese engineers in the Hanyehping Company who played such a role. Although the Hanyehping Company declined quickly in the late of 1920s, it had provided the only stage for the first generation of iron and steel engineers to exercise their technical ability in early twentieth century China, and through which an accumulation of prime technical know-how was achieved.

The case of the Chinese engineers of the Hanyehping Company provides a new perspective for discussion of the "Westernization Movement" (*yangwu yundong*). In our view, it is not enough to look only at the late Qing Dynasty when considering the Westernization Movement and the development of technology in China. One also needs to consider this subject through a longer historical time period.

Appendix

The Far Eastern Problem
(Yefah CHEN 程义法 CHENG Yifa)

[This historical document is reprinted from *Colorado School of Mines Magazine*, vol. 1, no. 5 (1911), pp. 4–5, with permission.]

The political dilemma between the West and the East will be probably the last vital problem concerning the human race. Tracing back our history, we can review some of the most critical stages of the human drama. The first notable one was that between the Persians and the Greeks; how the ancient Shah repeatedly threw immense troops into the democratic peninsula; how the brave Spartans won the last day, and how their inimitable record has excited wonder and admiration even to the present generation. The second was that between the Romans and Carthaginians; how the three wars, waging on land and on water, between the passages of the Alps and among the tribes of the Iberians, at last brought the African commonwealth into humiliation, and how "Carthage should be destroyed" has been practiced by many a statesman of the late ages. The third was the union of the 13 colonies and the independence of this great republic; how the brave warriors and the brilliant thinkers laid down for once and for all the foundation of this inseparable and irresistible union. The fourth contact began half a century ago and is going on, that between the East and the West. By reason of the population of the two races, the intricacy of the different governments concerned in and its far reaching consequences, this will be the greatest and the last disturbance among the family of nations and will foreshadow all others of the past history.

Through her successive adverse fortunes in forced wars, China on the eve of 1894 exposed her helplessness to the world, and her supposed strength and power once more passed into mystery. Thenceforth innumerable concessions, indemnity, request and demands came in black and white, but if unfulfilled, on the end of the sword. So much have the Easterners suffered; so much have the Westerners profited. The writer has often wondered how the winner could conscientiously exact such unjust treatment from his temporary down-trodden foe, while in the eyes of the Creator, both are his created and are therefore, by natural ties, brothers. In this connection we may recall the far-sightedness of the American statesman, John Hay.

When the nations were discussing the tearing up of old Cathay into piecemeals, seemingly that nothing but iron and blood could determine the supremacy of disputes, he, representing the Stars and Stripes, intervened and at last prevented such a rash step. Were such a resolution passed in the council of nations, the conquered will suffer bodily while the conqueror morally, tarnishing his conscience and rendering his moral sense dull and indifferent.

So much for the dark age of the present era. Japan, being a younger and therefore more active of the Asiatics, realized her paralyzed situation. Through her visitors, returned students and travelers, she noticed the superiority of the Western civilization. During the following 30 years she reformed old systems, learned new ways, abolished ruinous customs and installed profitable undertakings. Severe was the opposition, difficult was the trial, but she labored patiently, silently and consistently. In the meanwhile, Russia, being unable to obtain an ice-free port on the Baltic and on the Black, was concentrating her attention on eastern Asia. Korea thus became the buffer state between these two powers. Should the hermit kingdom fall into the hands of the czar, Japan would be sooner or later overrun by the Cossacks. Here, self-protection was necessary for self-preservation. The consciousness of appalling danger stimulated preparation against war which took place finally with unexpected end.

So much is for the awakening of the East. Japan has climbed up. The next question is: Is she going to be the leader of Asia? Her dealings in these 3 years have clearly demonstrated her unfitness. Her primary motive has been one of self-gratification. Being exhausted in the late war, she is trying all her means to restore her spent wealth, without due regard for the rights of other nations. Her secret unequal taxation of merchandise in Manchuria, her arbitrary building of unlicensed railways and her disguised merchants, spying forbidden and tactical places everywhere, have much lowered her esteem in the eyes of nations. Moreover, her population and her dominion is too insignificant for leadership. Can one man hold the voice of 20? She has advanced, indeed, but her advance is that of time, not of kind. Give China the sufficient time and she will outdo her wee sister in the long run. With the long and yet inaccessible coast line, China cold attack and defend, trade and communicate. With her inestimable natural wealth, she could develop and supply. Her size and her population alone is sufficient to watch over other nations in war or in peace. Nothing but time will prove the validity of the above supposition.

Granted that time and opportunity are both in her favor, some might still question her tendency, whether she would stand for might or for right. Since a nation is an aggregate of people, the latter's characteristics can largely determine those of the former. Why are the remarks of a Westerner on us? Are they not that we are peace-loving and self-satisfied? In fact it was self-satisfaction that kept us back in civilization, and peace-loving that make us to tolerate humiliation. Possibly nothing human is so unchangeable as the national character. The luxury of the Frenchman today is as famous as during the reign of Louis XVI. The sea-faring of the Englishman is as prominent as that by Sir Walter Raleigh. Possessing these qualities, China shall protect her own rights, but not intrude upon those of others. Unlike Japan, a casual success will stimulate her to look for rainy days, and resume her responsibility in the Eastern affairs.

Such is the destiny of China as assigned to her by the Creator. Shall America join hands with China for the uplifting of mankind? Has America not the same motives? Are you not peace-loving and satisfied with your puritan land? At present foreign aggressions are still going on. From the aggressions come disputes, from the disputes comes war, from war comes woe to mankind. The natural cycle of events will not cease until each nations keeps within her own bounds. Wisely you have declared: "America for the Americans!" Shall you not be wiser to help us to declare: "China for the Chinese!"?

Lastly, what is the highest sense of conquering a people? In ancient times, it was the enslaving of the conquered; in mediaeval, the control over the conquered; in modern, the trade with the conquered, but at present, the conversion of the conquered. Nothing but firm friendship can be derived from the similarity of belief. Shall you not convert us? Shall you not bring the lost sheep to your Master? We are ready to surrender before our Father. The day will come when light and truth shall diffuse into the most obscure corner of the globe. Then we shall see two nations, one young and one old, one on the right shore and one of the left of the mighty Pacific, shall preserve order and peace, shall hold the equilibrium of nations and shall see the cease of the talk of the Far Eastern problem.

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Chapter 16
Engineering and the Postcolonial: Historical Perspectives and Ethical Practices

Suzanne MOON

Abstract Can postcolonial methodologies help engineers function more effectively and ethically in a world made up of multiple modernities? This chapter uses the case of Indonesia to explore the ways that postcolonial memories of the past have shaped the interpretation of the significance of technology and engineering, and therefore technological values and identities of both engineers and the postcolonial publics. Furthermore, it asks whether postcolonial methodological interventions analogous to those used by social scientists and medical professionals to improve their own practices may aid engineers. Paying attention to deeper histories and questioning the practice and consequences of silencing are two ways that engineers can strengthen their ability to analyze technology- related conflicts, and to reflect on their relationships with broader publics.

16.1 Introduction

As scholars like Gary Lee Downey have cogently argued, a close look at the cultures of engineering around the world demonstrates significant diversity in values and practices (Downey and Beddoes 2011; Downey et al. 2007). The values within particular engineering cultures are themselves strongly shaped both by historical experiences and the ways that people individually and collectively interpret histories. To put it in terms popular among historical scholars, engineers like all other people engage in memory practices, remembering and interpreting the past in ways that actively inflect their choices and actions. Remembering the past may powerfully influence the ways that people interpret or shape technologies, especially the way they interpret technologies ethically, as morally defensible or indefensible, as good or bad for wider society, or more subtly in the ways they debate whether and under what circumstances benefits outweigh costs. This chapter uses the history of Indonesia to investigate how postcoloniality, and memories and interpretations of

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colonialism have shaped values and interpretations about technology in postcolonial settings. How have postcolonial perspectives and memory practices shaped the interests and practices of engineers as well as their understanding of the social costs and benefits of technological change?

Investigating this question is meant to contribute to the literature that explores the diverse ways of thinking about engineering that coexist in the world. Understanding these differences, and the histories that help produce them offer engineers, wherever they may work, meaningful insights about the global engineering environment. Investigating history can be especially valuable when commitments to particular technologies, technical approaches, or wider sociotechnical arrangements emerge from social concerns with deep historical roots. Such concerns are not easily overturned or swept away by technological fads or counter narratives with little local resonance.

Especially when engineers face controversial projects, understanding history may be the difference between a sustainable engineering solution and one that will produce negative consequences, or fail altogether. Yet attention to the conditions of postcoloniality may offer critical perspectives that go even deeper than this. Postcolonial critiques by humanists and social scientists (Chakrabarty 2000) have already produced practical new approaches in fields like medicine (Dutta 2008; Kirkham and Anderson 2002). Might they do the same in engineering, perhaps by offering new thinking that could productively reshape engineering practices in the postcolonial world and beyond? By considering the ways that postcolonial environments shape social attitudes towards different kinds of technologies, and by taking seriously the thoughtful critiques that have emerged from the writings of postcolonial scholars, engineers may be able to find new ways to pursue their professions and act meaningfully in a complicated world.

16.2 Postcoloniality and Technology

It is not surprising that moments of significant and widely visible technological change may generate questioning of both technological and social values. Likewise, at some moments questioning the availability of technology and its sufficiency for social needs is a way to subtly (or not so subtly) protest wider political order; drawing a link between material and political power can make more real for diverse audiences the consequences of particular forms of political order (Jasanoff 2004). Both of these circumstances pertained in many parts of the parts of the world under colonial rule in the early twentieth century. Colonial interpretations of technology were frequently durable; some critiques and concerns originating in the colonial period endure to the present day.

One of the most important, lingering consequences had to do with the relationship between the Dutch system of rule and economic opportunity in Indonesian society. That is, did the Dutch stack the deck in their system, making it impossible for a talented, ambitious Indonesian to attain financial success? In the early twentieth-century, there was widely visible technological change in Indonesia, especially in urban areas. Automobiles, movie theaters, and eventually radio became visible in everyday life (Mrázek 2002), while in the agricultural industries that produced much of the colony's wealth, including sugar and rubber, scientific plant breeding, and new machinery used for post-harvest processing all signaled important shifts in the technological foundations of production (van der Hoogte and Pieters 2013). Yet for all of the visible change and the widely promoted idea that the Netherlands Indies colonial government intended to improve the welfare of ordinary Indonesians, a significant gap existed between the average income of a European and the average income of Indonesians. Social critics, both Indonesian and Dutch, argued that the whole system of Dutch rule and organization of colonial life was designed to prevent Indonesians from really profiting from new techniques or technologies (Moon 2007).

One example was an aborted attempt by the Indies Agricultural Extension Service to teach smallholding indigenous farmers how to grow sugar cane which would then be sold to planters or on the domestic market. For many years, European planters had controlled most sugar production in the colony, using indigenous labor and working on land leased from indigenous farmers on a 3 year rotation: for 1.5 years the land was used by the plantation and for 1.5 years by the farmer who owned the land. Farmers were compensated not according to the value of the sugar harvested, but according to the much lower price that a hypothetical rice crop would have produced in the same time period. By adopting smallholder sugar planting techniques—techniques rather different than those used on large-scale holdings, small farmers could produce a more remunerative crop. Acting on new ideas about agricultural economics and social welfare, agricultural extension agents in the 1920s began to hold classes for farmers to teach them smallholder sugar production. European planters objected. If farmers could make better money growing sugar, why would they ever agree to lease their land? Planters used their considerable influence with the government to make such courses illegal. A subsequent reorganization of the Department of Agriculture changed the way that extension agents reported to their superiors, making it difficult for even the most idealistic young technologists to continue such work (Moon 2007). It is no wonder therefore that many Indonesians treated with skepticism claims that new technology represented an improvement in their own lives or proof of the government's beneficence.

These critics of the colonial system interpreted the value of new technologies and their implementation in society within a broader framework of concerns about justice and its relation to the distribution of the benefits of a given technology. Notably, critics were troubled not with the Dutch people per se or with European technologies in principle, but with the colonial system that they blamed for excluding Indonesians from the benefits the technology could provide. This was no nativist movement. Indeed, Indonesian interpretations of the colonial system and the benefits of technology were developed very much in dialog with Dutch intellectuals and colonial critics. The problem was not the nature of the technologies but the nature of their deployment and control.

Consequently, the new technologies, or even new forms of technological education were frequently greeted with both interest and suspicion. In the 1930s, a lively public debate about industry in the Indies—specifically the paucity of industries owned and operated by indigenous Indonesians—raised similar questions about the injustices associated with the deployment of new technologies in the colony. Nationalists like Sukarno argued that until colonization ended, little would ever change, using a narrative of material and economic justice to promote anticolonial action (Moon 2007). Throughout this period therefore although Indonesians were surrounded by the rhetoric of the value of technological improvement, a high-profile, widely-shared narrative about technology emphasized the fear that the colonial system artificially withheld the benefits of new technologies from Indonesians.

Moving forward to the postcolonial era, many Indonesian leaders saw a key job of the new nation to be the spread of economic and technical opportunities which would facilitate the natural emergence of the just society that colonialism had suppressed (Sutter 1959; Hatta 1972). As people in Indonesia struggled to define Indonesia's national identity and the promise of the postcolonial nation, many assumed that the absence of colonial control would open the doors to greater economic and technical opportunity, and achievement. Yet at the moment when leaders took control of a newly postcolonial nation, the definitions of equity and justice became the focus of attention. What was needed to create economic equity? Was it, as first president of Indonesia Sukarno asserted, ownership of businesses by Indonesians, and perhaps additional government advocacy of particular technological sectors that would reduce dependence on foreign suppliers (Legge 1972)? Should Indonesians reject the capitalism that powered inequalities in the colonial period altogether and embrace Communism as some called for during Indonesia's first constitutional convention? Perhaps Indonesia ought to stress the empowering possibilities of cooperatives to build the Indonesian economy on the widest possible foundation, prioritizing the economic needs of the lower classes, the so- called "small people", as Mohammad Hatta argued in his writing on cooperatives (Hatta 1954)? Achieving consensus about the right measures to indicate the achievement of economic equity was equally difficult. Certainly diminishing poverty was a crucial indicator, but the existence of poverty remained stubbornly intractable. Economic justice lay at the heart of the colonial critique and therefore at the core of the identity of the postcolonial nation, yet the haziness of the definitions of equity and justice underscored political and aspirational divisions deep in Indonesian society. For this reason, debates about economic and technological priorities, and even debates about the value or desirability of particular technologies frequently centered on the issues of economic justice, and the good of the nation.

Public discussions of technologies in magazines, radio, and later television in postcolonial Indonesia shaped public perceptions of technological change. When debated in terms of economic justice, technologies were frequently meaningful as potential solutions to problems of justice, potential problems, or as mirrors through which wider problems of injustice could be revealed. For example, in the early 1970s, audio cassettes and simple recording technologies spread like wildfire through Indonesia; soon shops and market stalls were full of audio cassettes containing pirated music, taped from expensive vinyl LPs. *Tempo*, a news magazine modeled on *Time*, explored the consequences of this new technology in an article entitled “Following the Path of Piracy” (“Menjusuri Djejak Pembadjak” 1971). The questions raised were largely about the ethics of copying. The reporters acknowledged that illegal audio cassettes harmed the living of some of those in Indonesia’s recording industry who received no royalties from these illegal tapes. But interestingly, the reporters also made a strong case for the wider social value of the cassettes. They highlighted broad social access to inexpensive music as one of positive results of this new technology: family celebrations like weddings could now use recorded music when live musicians were too expensive; people with lower incomes and those in rural areas far from urban record stores could now enjoy new music more readily. Beyond consumer access, they also pointed out the opportunities that this relatively inexpensive technology offered to energetic young entrepreneurs. This last point pivoted on the issue of economic justice. At a moment when President Suharto’s young New Order government was soliciting foreign investment and focusing on building large industries, the idea that some technology—even if illegal—could help “small people” get ahead served as both a critique of existing conditions (because small business people had to resort to crime to get ahead) and an endorsement of this technology which could in some small measure even the scales. The article went on to undermine their earlier acknowledgement of the harm the cassettes caused by pointing out that many record industry executives themselves routinely pirated music from India, Europe, and the United States. Thus, this article about a new consumer technology, audio cassettes, made technology a mirror to demonstrate social inequities and hypocritical legal standards that reinforced rather than fought to overturn those injustices.

Issues of economic justice and national good were particularly visible at the site of national projects, such as the construction of the Krakatau Steel mill in the city of Cilegon in the early 1970s. As a state-owned firm, Krakatau Steel was important to Suharto’s New Order economic plans because it would provide a key local resource, steel, needed for countless other industries (Moon 2009). As such it symbolized for officials Indonesia’s growing independence from foreign products and expertise, a potent image of national development at work. Yet public discussion of its construction consistently questioned some of these very points. A German firm had been hired to help build the site and the state had spent a great deal of money providing what some saw as lavish housing to accommodate foreigners, including entertainment venues like cinemas and golf courses (Arndt 1975). Where was Indonesia’s independence from foreign firms? Why was money spent on raising the living standards of foreign engineers (Moon 2009)? Likewise, Indonesian executives were paid exorbitantly and showed off their extravagant lifestyles including one executive who commuted daily to the building site by helicopter (Yuarsa 2004) even as the people of the city seemed to be getting very little from the building process. When an Indonesian organization interviewed the people of the area they discovered that most saw the mill as a place for foreigners, meaning people from Jakarta as well as from other countries, and therefore not really something that was designed to help ordinary people (LP3ES 1975). Clearly issues of economic justice framed public interpretations of technology, calling into question not only the value of technologies, but the priorities of the postcolonial nation. Because technological change was so often interpreted through the lens of economic justice, engineers in postcolonial Indonesia could not avoid seeing their own work in light of these larger issues.

16.3 Postcolonial Engineers

Engineers in postcolonial Indonesia, like engineers in many other postcolonial settings (Valderrama et al. 2009), understand their role as not simply one of building technologies, but also of providing an essential service for the growth and development of the nation. Crucially, in these settings, many engineers do not see themselves as passive actors, waiting to be told what is vital to the nation, or directed from above. In Indonesia, engineers in the 1970s for example, especially young engineers, questioned the larger context of their work and how it fit into the tangled context of economic justice. The idea of contributing to national growth could pull in them in rather different directions. Suharto's New Order government had by that time chosen to move aggressively away from the unsuccessful import substitution policies of earlier years in many areas of Indonesia's economy, welcoming foreign investment, foreign technologies, and foreign consumer goods. Suharto's government endorsed partnerships between foreign and Indonesian industries to bring both money, and new technologically up-to-date industries to the country. Indonesian engineers played a role in many of these enterprises. Working for such businesses was not just a good job for an engineer, although it was that, it was also clearly framed in official circles as contributing vitally to Indonesia's development (Amir 2013).

However, as New Order planning and industrial growth progressed, for some critics, doubts crept in—about the bribes and corruption that seemed part and parcel of the wheeling and dealing with foreign companies, and about the ongoing problems of poverty that continued almost unabated and which seemed to be getting little real attention from the New Order government. Some engineers felt compelled to address the problems of what Indonesians call the "small people": the poor. In the 1970s for example, the magazine *Tempo* featured an article on an engineering student organization and their independently developed plans to address water distribution problems in several villages near to their university ("IMTI Membenah Diri", *Tempo*, 12 June 1971). This self-organized project seemed to be as much critique as it was a plan of specific action, as the interviews with students suggest that they felt compelled to address these problems because they were being neglected by authorities. Although it may have been true in this case, it is not true that the New Order government entirely neglected villages, at least villages on Java. What is significant here is the tone of self- presentation: these young engineers saw themselves as problem-solvers who felt an obligation to go beyond self-interest in their work. The reporter re-emphasized the link between engineering and the fate of the nation by highlighting both the technical novelty of the proposed design and the social responsibility of the engineering students as reasons to be optimistic about Indonesia's future ("IMTI

Membenah Diri", *Tempo*, 12 June 1971). The long history of thinking about economic justice as a necessary component of the postcolonial nation, as well as the ambiguity and vagueness of the concept, informed the ways that engineers could think about themselves, their work, and their wider social obligations. While some could take satisfaction in contributing to New Order industrial development and hope that poverty would slowly erode under the pressure of economic change, others would choose to directly address problems of poverty in their work, seeking direct solutions and by paying attention to the issues, making the reality of those problems more widely visible in Indonesian society. Both approaches were easily understood as building the nation, but difficult to pursue simultaneously.

In the *Tempo* article about the student engineers, it is no accident that reporters praised students equally for their social responsibility and the novelty of their technical project. Creativity and innovation in technical fields was for many postcolonial nations an important measure of national growth, vitality, and independence (Abraham 1998). Indonesia was no exception as creativity was a central focus of debates about Indonesia's future; popular discussions of creativity tended to emphasize the ways that harnessing Indonesian intellectual capital could push the whole nation forward economically and technologically. Such beliefs fought against stereotypes that had emerged during the colonial period in the early twentieth century. Some colonial commentators from the hardline colonialist side of Dutch politics tended to portray Indonesians as indolent, poor at business, and lacking initiative, drive, and the capacity for meaningful technological creativity without help from the Dutch (Moon 2007). These stereotypes had long-term effects on Indonesian identities. As late as the 1960s and into the 1970s and 1980s, both Indonesian and foreign researchers studied the relationship between entrepreneurial and technical abilities and Javanese culture, usually rejecting colonial mythology, but nevertheless trying to understand what seemed like ethnic disparities in innovative practices (Siregar 1969; Dunham 1992). Although the issue of Indonesian ownership of businesses was high profile throughout the colonial and post-colonial periods, the issue of technological creativity as a problem for Indonesians became most evident starting in the 1970s and 1980s.

Although historically the import of foreign technologies generally did not seem to aggravate any concerns about Indonesian creativity in earlier years, the plethora of foreign businesses and the complexity of thinking through the balance between foreign experts and engineers and local innovation began to get more press. Although the issue of creativity and innovation strikes directly at an engineer's identity as a skilled practitioner, in no way did engineers respond with a single voice to issue of engineering employment, and opportunities for technological innovation (Barker 2005; Amir 2013; Thee 2006).

One anxiety a few officials expressed related to technical creativity was whether Indonesia was too dependent on other countries and was therefore marginalizing its own creative powers in favor of creating low-wage jobs (Thee 2006). In the 1980s and 1990s, Minister of Industry B.J. Habibie (who later became Suharto's vice-president and then Indonesia's third president) pushed hard to "Indonesianize" some technologies, to develop the skills and capacities of Indonesian engineers, to produce high profile technologies that would be designed specifically for Indonesia, and to make Indonesian creative input a significant part of the business. Habibie, a German-trained engineer who had returned to Indonesia determined to build the skills and capabilities of Indonesia's small pool of engineers, had earned Suharto's trust and was therefore given remarkable freedom to push this agenda (Amir 2013; Habibie 1991). To this end, he created a scholarship fund to send many of the brightest young engineers overseas to study in the Netherlands, Germany, France, the U.K. and the United States, with an eye towards improving engineering education in Indonesia for the next generation. His most famous project was Indonesia's national airplane project. Designed and built entirely by Indonesians, it also responded to Indonesian conditions, by being able to take off and land from much shorter runways than the international norm, a necessity on some locations within Indonesia (Amir 2013). Although the project was successful and many people took pride in the achievement, the idea of "all-Indonesian" design received a somewhat mixed response in Indonesian society. A news item from 2012 about a technical school that had designed an all-Indonesian SUV and was looking for investors to put it into production inspired a wide range of comments, from those who liked the idea and those who found it needless and wasteful of local resources (Brata 2012). For engineers in Indonesia, satisfaction with their work and accomplishments may well be inflected by complicated perspectives on the relationship between national greatness, and technological skill.

16.4 Toward Postcolonial Engineering

Histories can offer a greater understanding of the motivations that drive individual engineers as well as the wider social response and debates that may surround engineering projects in the postcolonial world. Yet there is more to be gained from considering the postcolonial in relation to engineering and the wider ethical implications of technological activity. If we shift our attention from analyzing the character of postcolonial life to considering the possibilities and challenges that postcolonial methods of criticism might offer to engineers themselves, it may open up new avenues for analysis, especially in projects that produce conflict. Postcoloniality is about more than simply reacting to the colonial past. It also represents a way of moving forward through critical engagement that attempts to overcome persistent inequities by questioning assumptions, and frames of meaning that often unintentionally reproduce those inequities, or render them invisible and thus not open for discussion. In the last 20 years historians, anthropologists and other social scientists have confronted the ways that their own scholarship has silenced subaltern people, privileging the stories of elites and perpetuating the kinds of injustices that they seek to criticize. To make a start at correcting this, social scientists have tried to bring the voices and actions of subaltern peoples back into the history without garbling them or ventriloquizing. Would something similar serve engineers? Is it useful to imagine ways to decolonize their own practices and find a new basis on which to operate?

The first methodological intervention is, as above, to consider how longer histories inform interpretations of technologies, and how the social and political relationships are likely to be affected by a given technology or technological project or design. This may be particularly important with technology projects that have a clear geographical site, and therefore a well-defined local sociopolitical environment, as is the case with infrastructure projects. The crucial step is to recognize that engineering is always a heterogeneous process, not just the making of technology but the building of particular social and sometimes political relationships to support a technology (Law 1987). Thoughtfully incorporating social knowledge into the design process means acknowledging and thinking through the knowable consequences of technical action on affected communities in a rigorous way. Rigor, I argue, requires knowledge that goes beyond a snapshot of contemporary debates but looks for deeper social currents that may profoundly affect the acceptance, use, or ultimate value of a particular design. Since no technical action can proceed without consequences for the humans involved, understanding the social environment in a thorough way may in some cases be the difference between a design that works harmoniously in a given environment, and one that deepens existing social conflict or creates new kinds of conflicts.

Consider for example the contentious process of mining West Papua, or contemporary oil pipeline projects like the Keystone XL project in North America. Large-scale mines, like the gold and copper mines in West Papua in Indonesia are of course massively disruptive to people living in the area: traditional use of local resources may be curtailed or made impossible, pollution from tailings may have ripple effects on environments and people, and cultural, social, and economic disputes between incomers and residents are common (International Crisis Group 2012; Aditjondro et al. 2000). The question of whether or how local people should be compensated or benefit from mining is profoundly politicized. All of these issues make mining operations in areas with even small populations contentious. Yet in Indonesia, a further serious problem is the political history of Papua itself. Many Papuans question their annexation by Indonesia in 1968, and reject Indonesian sovereignty, particularly the right of the Indonesian government to make decisions concerning resources (Elmslie 2002). Foreign mining operations then inevitably become embroiled in a battle in which the question of "benefit" is impossible to separate from questions of political freedom. The consequent protests could have been easily predicted by anyone who understood Papuan histories and contemporary political cultures. Likewise in the Keystone XL pipeline, the connection between perceptions about the likelihood of devastating accidents, and serious, long-term problems with political sovereignty and the use of their own lands among First Nations peoples in Canada turned a technical project and a set of technical decisions into massive, multinational controversy ("Keystone XL Pipeline" n.d.).

In Papua, the Indonesian government used violent force to keep mining operations working (International Crisis Group 2012). The future of Keystone XL and responses to it should the project move forward as planned, remains an open question at the time of this writing. Are these really engineering problems, or wider problems of corporate or state decision-making and priorities? Certainly, these problems are not generated simply by the engineers working on site. In some situations, it may not be possible for an engineer to satisfy the demands of their employers without creating a negative outcome for others. My aim is not to blame engineers as a group or to imagine that all problems have technical solutions. However, the ability to solve a problem requires a clear recognition that the problem exists, such as an acknowledgement of the likelihood of violent outcomes at the confluence of certain social, political, and technical circumstances. At the very least, a realistic understanding of the historical and contemporary situation and the technology in question would offer to individual engineers a clear view of at least some of the consequences of their work, allowing them to decide for themselves if they wish to participate. At the most however, especially when faced with less intractable problems than those posed by mining in Papua or moving oil across sovereign lands, engineers may be able to apply their skills and abilities mindfully, finding solutions that can minimize conflict and hardships. People working on technical projects owe it to themselves, their employers, and the people their work affects to assess the sociotechnical world they are creating as realistically as possible and this means a willingness to look unflinchingly at the ways that technologies become embroiled in power relations.

The second methodological intervention is to consider the problem of silencing. One of the most important concerns of postcolonial scholars is to call attention to the ways that colonial relationships silenced certain people in society while privileging the interpretations and beliefs of the powerful; colonial power was reinforced by silencing some people, whether the very poor, those whose belief systems diverged in uncomfortable ways from leaders, or people whose voices were dismissed based on gender, ethnicity or other elements of identity (Chakarabarty 2000). Scholars have spent many years grappling with the consequences of this kind of silencing in our own narratives, as the written records of colonial officials easily overwhelm hard-to-find records of silenced people. Even the framing of the research questions scholars ask are strongly shaped by the power relations of the past. Embracing postcolonial methods requires especially an awareness of the various acts of silencing, and ways to counteract them without reproducing the unequal power relations that created the problem in the first place.

For engineers as well, an awareness of how their own work may be implicated in acts of silencing, even when acting with the best of intentions, can lead to more productive ways to understand and resolve conflicts. Scholars have noted that since the professionalization of engineering in the late nineteenth century, engineers in most parts of the world, although profoundly diverse in some respects, have tended to come from the middle or upper classes, and to acquire middle-class attitudes, aspirations, and values (Adas 2006). The relatively privileged place of engineers in many settings makes it easy for them to overlook or deny the concerns of those whose position, education, and world views are profoundly different. This is especially true when differing perspectives may threaten the ability to start or complete a project. The tendency of engineers to speak for the poor, and define both problems and solutions according to middle-class values may seem pragmatic and a valid privilege given the technical knowledge that engineers possess. Yet acts of silencing and marginalization refuse discussion, compromise or even permission to speak to those whose lives are deeply affected by technical projects, an act which is ethically troubling.

These acts of silencing, even the fact that they are often regarded as mere pragmatism have deep historical roots. In some societies, more than class may separate engineers from local populations: they may have different ethnic backgrounds, political values, or even different languages. To cross such a cultural gap is enormously challenging, even frustrating. When I once asked a roomful of Indonesian engineering undergraduates what problems they would identify as being of particular concern for Indonesia's technological future, their first, and very fast, response was the "underdeveloped, superstitious" people of Indonesia who were too traditional to function properly or contribute to a modern society. Their response reiterated developmentalist and indeed colonial dichotomies that divided populations according to whether they belong to "modern" or "traditional" sectors. By placing certain populations in this category of traditional, these students both defined the people themselves as a problem to be solved, and dismissed these "traditional" people's ability to contribute anything meaningful to a discussion about Indonesia's future. Historians, anthropologists, sociologists and other social scientists have strongly argued against such dichotomies, pointing out the ways that certain behaviors or systems of rationality deemed "traditional" are in fact dynamic, changing systems of belief that reflect diverse reactions to the conditions of modernity (Chatterjee 2004; Mukharji 2012). Many scholars will instead talk about postcolonial nations as sites of multiple modernities. Foundationally, we are all modern, all engaged in dialog with the needs, problems, and promises of modernity. Labeling and dismissing some groups as unmodern, incapable of rational speech or insufficiently responsible to engage in issues that affect them recreates colonial practices of silencing, and sows the seeds for divisions that undermine social cohesion. By either dismissing these world views as irrelevant, not thinking to consult the poor, or speaking for the poor by reinterpreting their claims through the language of scientific rationality, engineers are reinforcing social and political inequities and divisions and silencing subaltern groups in just the way that Indonesians felt silenced by colonial authorities. That most do so without malice and with the best of intentions is clear. What are the possibilities for an alternative approach? How should engineers engage with populations separated from them across gulfs of class, culture, and power, as they go about their job of designing technological solutions to important problems?

Development agencies have long recognized problems like this, calling for participatory development methods that provide more agency to people affected by development projects. Yet even here, it is not an easy problem to solve, as agencies cope with priority conflicts, surprising (to them) uses of technical resources they provide and the thorny question of defining appropriate participation in the first place. Should hierarchically-organized communities be forced to adopt democratic methods? Should development experts with commitments to issues like gender equity, or democracy concede a method of participation that violates their own deeply held beliefs? Clearly, calling for participation, while certainly acknowledging the issue, does not itself provide ready answers to all problems. And indeed, there is no formula to resolve all such problems. But attention to the existence of the problem may lead to valuable new ways of engineering in the world.

16.5 Conclusion

As STS scholars have long argued, engineers are heterogeneous engineers - in the process of engineering systems or objects, they are also engineering social relations. This observation has been deeply meaningful for the study of engineering ethics, enlarging the scope of ethical investigation in ways that emphasize engineers' relationships with varieties of publics. Rather than being a study of engineering ethics in its strictest sense, this essay highlights instead the ways that historical experience can inflect the ethical interpretation of technologies. In a significant way ethical questioning arises and is co-produced with technologies themselves, sometimes in enduring ways. Memories of the past shape assumptions about and responses to present day technologies and inform identities, both singular and collective around technology projects. Therefore, understanding the past can offer helpful insight into questions such as: why are some common engineering tradeoffs more palatable in some setting than others? Why do certain types of conflict surrounding engineering projects seem to reappear again and again? How can a project which is socially uncontentious in one place, create such profound discontent elsewhere? Understanding history offers useful perspectives on these questions, especially in situations where engineers are addressing publics who differ in significant ways from themselves. In the case of the postcolonial societies studied here, the experience of colonialism continues to echo, reflected in ways that the social value of technologies are discussed, the way engineers understand the significance of their work, and in the fractures of colonial society.

Many engineers have a strong desire to use their skills to solve problems and ultimately to leave a positive mark on the world, even as they have a deep technical understanding of the inescapable tradeoffs that have to be made in any technological undertaking. Scholars of engineering ethics, whether engineers themselves or humanists, systematically and rigorously explore the responsibilities of engineers based on a realistic understanding of both technology and society. The idea of a postcolonial engineering method taken up in this essay uses the ethical self-questioning that social scientists have engaged in as a model for expanding the kinds of analysis engineers might ask to encourage further reflections on the question of engineering, silencing, and the consequences of sociotechnical action in a world made up of multiple modernities.

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Chapter 17

Conflicts and Adaptations in Technology Transfer to Modern China: The Jiaoji Railway Case

WANG Bin 王斌

Abstract In 1897 Germany occupied the Jiaozhou Bay by force and in 1899, a German syndicate founded the Shandong Railway Company to construct the Qingdao-Jinan Railway. In the initial construction period, brutal behaviors by Germans led to several violent confrontations with local people. The conflicts during construction can be attributed to cultural factors, legal issues, and economic interests. In 1900 the Jiaoji Railway Regulations were signed to help normalize the behaviors of the Shandong Railway Company. The company cooperated with local authorities to resolve conflicts and to build roads in major cities and towns. The conflicts and adaptations during the Jiaoji Railway construction exemplify interactions between both parties during a particular technology transfer in the context of colonization.

17.1 Introduction

Scholars have numerous definitions of technology transfer, and activities as diverse as invention, trade, spying, copying, empire building, and military conquest can all contribute to it. For one influential scholar technology transfer is "the process and result of transferring the technology ideas, skills, processes, hardware and systems across a variety of boundaries—national, geographic, social and cultural, or organizational and institutional" (Seely 2003, p. 8). Using this definition, the number of books on technology transfer clearly began to increase dramatically in the United States after 1960, and American historians produced a large number of case studies on such topics as the spread of the Industrial Revolution from England to America, industrialization in the Soviet

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Union and Japan, technology development in former European colonies, and technology transfer activities in developed nations. These studies often argued that successful technology transfers depended on exchanges of people, not just machines, drawings, patents, or other technical artifacts. Creative social adjustments were also often involved. Consequently, scholars now pay more attention to highlighting the two-way interaction between technology and society or culture, rather than the mere impact of technology on society.

Technology transfer is nevertheless a new research topic in China. Introducing Western technology was a main approach for the Chinese to modernize. Modern technology transfer from the West to China happened in the context of Sino- Western conflicts, which were also reflected in politics, diplomacy, economics, and culture, with various factors affecting and hindering the transfer. In the 1970s, American scholar Shannon R. Brown made several case studies of technology transfer to China during the second half of the nineteenth century, probing into the main obstacles; she concluded both economic and political factors played important roles (Brown 1978, 1979a, 1979b). Chang Jui-Te, a scholar from Taiwan, examined problems arising from the introduction of railway technology, including both hardware technology in engineering and software technology in management (Chang 1993). Zhang Baichun and his co-authors from mainland China closely investigated interactions between technology and economics, politics, diplomacy, and state security by choosing three typical cases to describe and analyze technology transfer from the Soviet Union to China (Zhang et al. 2004). In recent years, a team led by Zhang has continued to study these connections with a series of studies on technology transfer from the West to China through cases of artillery, railway, and telegraph (Sun 2014; Wang 2012; Li 2013).

Among all technologies introduced into modern China, the railway occupies a vitally important place. Railway construction began in China in the 1870s and experienced difficulties. At the end of the nineteenth century, imperialist powers started violently dividing up China. By offering railway loans to China and asking for the right to operate railways, or by direct investment in railway construction, they established spheres of influence. The Jiaoji Railway was the outcome of German colonial expansion. It started from Qingdao, the Germans leased territory and traversed Shandong province in central-eastern China. There are only a few monographs on the Jiaoji Railway (History Department, Shandong University 1961; Schmidt 1976; Dost and Hartwig 1981), though there is much research on the history of the Sino-German relationship and the leased territory of Jiaozhou (Wang 1988; Seelemann 1982; Mühlhahn 2005; Warner 1994, 1996). With the aid of archives about the leased Jiaozhou territory at the Qingdao City Archives, the present study explores the construction and operation of the railway, focusing on conflicts and adaptations arising from the construction period, and analyzing how both parties to the technology transfer (Germans and Chinese) interacted and adapted to the conflicts and changes brought by the new technology.

17.2 Overview of the Construction and Operation of the Jiaoji Railway

After China's defeat in the First Opium War of 1839–1842, it was forced to open up to the West and began to lose more and more of its sovereignty. Treaty ports were opened as channels into the huge Chinese market. The further efforts of Western powers to connect China's coast and its inland markets by railways was frustrated until the Sino- Japanese War of 1894–1895.

In the latter half of the nineteenth century, with its economic and military strength increasing, Germany began to strive for external expansion and world supremacy, and these acts were mainly represented in its rapid expansion in China (Schrecker 1971, p. 1). As the German interest in China grew, commercial circles and the German navy asked for the creation of a foothold in China. After a long investigation and extensive preparation, the German government chose Jiaozhou Bay, which was located in the south of the Shandong peninsula. From the point of view of Germans, Jiaozhou Bay was not only a fine harbor, but had a hinterland with economic value, with abundant mineral resources such as coal, and a potential sales market. German geologist and geographer Ferdinand Freiherr von Richthofen, who had travelled in most of the provinces of China, proposed in his book *China: Ergebnisse Eigener Reisen und Darauf Gegründeter Studien II* (1882) that a railway should be constructed from Jiaozhou Bay via the coal fields of Shandong and Jinan, the capital of Shandong, toward Beijing and Henan (Richthofen 1882, p. 226). This proposal had a significant influence on Germany's choice of Shandong as its sphere of influence.

In November 1897, two German missionaries were killed in Jüye in southwestern Shandong. Germany took this incident as an excuse to send troops to take over Jiaozhou Bay. On March 6, 1898, Germany and China signed the *Jiaozhou Lease Treaty*, in which the Chinese government leased Jiaozhou Bay to Germany and granted it the right to construct railways and exploit mines in Shandong. On June 14, 1899, a German syndicate founded the Shandong Railway Company to construct a railway from Qingdao (the base of Jiaozhou Bay) to Jinan. Germans named this the Shandong Railway; Chinese called it the Jiaoji Railway.

Construction began in August 1899 and the railway was wholly put into use on June 1, 1904. It was 434 km in length, with a mainline from Qingdao to Jinan of 395 km and a branch line from Zhangdian to Boshan of 39 km. Construction was made easy by a geography of plains and gently rolling hills. Numerous rivers nevertheless required bridges and culverts. Rails, sleepers, bridges, locomotives, wagons, and telegraphs were primarily of German manufacture; most engineers and technicians, were also Germans. All earthwork and most masonry projects were outsourced to Chinese labor due to the low technical requirements involved. Bridge construction was entrusted to the professional bridge company Gustavsburg (Wang 2012, p. 103). At the same time, Germans also initiated mining and established telegraph and postal services in Shandong.

Gross income of the Jiaoji Railway increased from 1.91 million Mexican silver dollars in 1905 to 4.13 million in 1913, with approximately 70% of this being attributable to freight transport. Transported goods consisted of three main categories. First was coal, which took up more than half of the freight total. Second was agricultural and handicraft products such as soybeans, oil, cotton, silk, and porcelains. Third was imported industrial products, such as petroleum, metal, machines, wood, cotton products, lime, sugar, match, and cement.

After the outbreak of World War I, in November 1914 Japan declared war against Germany and seized control of Qingdao and the Jiaoji Railway. At the 1919 Paris Peace Conference after the war, Japan assumed German rights in Shandong with the support of Britain and France, and the *Treaty of Versailles* formally transferred these privileges to Japan. This act directly triggered the May 4th Movement in China, and Chinese representatives refused to sign the treaty, resulting in their rights to Shandong being suspended. It was not until the Washington Conference at the end of 1922 that the Chinese Government resumed control of Qingdao and the Jiaoji Railway.

17.3 Confrontations During Early Construction Period

Shandong was a densely populated province in which the populous relied on agriculture and the land as the basis for living. Railway construction across farmland was thus bound to cause conflicts. In addition, the preaching activities of German Divine Word Missionaries in southern Shandong aroused local opposition. German occupation of Jiaozhou Bay gave rise to even stronger reactions in Shandong. During the initial period of railway construction, the brutal behaviors of Germans aggravated conflicts with local people, leading to severe violence.

A first confrontation occurred in early June of 1899 as the Shandong Railway Company conducted route surveys in some villages of Gaomi and in the process disturbed many family tombs. Destroying ancestral graves had always been taboo in China and the German provocation stirred up resistance from local people, giving rise to several small-scale conflicts (Liu 1986, pp. 88–89). On June 18 at Dalü village in Gaomi, a worker hired by the railway company insulted a young village woman on the market. Villagers beat the worker, and then pulled out the surveyor's poles and gathered around the railway company office in Gaomi. Heinrich Hildebrand, head of the Qingdao office of the Shandong Railway Company learned of this and hurried to Gaomi from Qingdao, asking the magistrate of Gaomi to restore the poles and investigate those who beat the worker, but the magistrate ignored him.

Hildebrand returned to Qingdao and asked the German governor of Qingdao, Paul Jaeschke, to send troops to protect the railway and its staff. On June 24, German commander Hauptmann Mauve led 80 naval soldiers and 15 cavalry soldiers to Gaomi, where they looted two villages and Gaomi itself, killing more than 20 villagers and injuring numerous others. On their way out, they burned all the books in the Gaomi Academy of Classical Learning (Chinese Academy of Social Sciences and the First Historical Archives of China 1983, pp. 32–33).

After the conflict, the governor of Shandong, Yü Xian, sent officials to Gaomi to investigate the matter and negotiate with representatives from the company and German troops. Meanwhile Yü Xian wrote a letter to Jaeschke, asking him to follow the *Jiaozhou Lease Treaty* and establish regulations concerning railway and mining matters with the Zongli Yamen (or Foreign Ministry). Jaeschke ignored Yü Xian's request and asked for compensation for the Germans (the Chinese Academy of Social Sciences and the First Historical Archives of China 1983, p. 10). In July 1899, an agreement was reached between China and Germany that stipulated that China should compensate Germany for the poles and military expenses with a sum of 4500 taels. The agreement also imposed a duty of protection for the railway on local officials, but it did not give China the right of control over the railway, nor did it place restrictions on the Shandong Railway Company. In the long run, the agreement did not accomplish anything substantial, and the railway company was still arbitrary in its deeds with no consideration of local customs of *fengshui* (geomantic siting) or taboos. At the end of June 1899, railway construction resumed. After 2 weeks, German troops left Gaomi, leaving 12 cavalry soldiers to protect the German engineers (Schmidt 1976, p. 72).

A second confrontation occurred in December 1899 during the construction of an embankment enabling the railway to proceed to the Haoli area of Gaomi, which featured low- lying areas that easily flooded. Villagers asked the railway company to change the route or build more culverts to discharge the water (Liao and Luo 1987, pp. 100–101), but the railway personnel ignored this request (Yuan et al. 1928, p. 25) with an excuse of it being too costly (Biener 2001, p. 44). The villagers fought against the foreigners in January and February of 1900, with people gathered again to stop the construction in several villages of Gaomi, and attacks on the Gaomi office. Engineers had to flee and railway construction was suspended. The construction site near Jiaozhou was also threatened and Jaeschke sent troops to keep order (Schmidt 1976, p. 77).

17.4 Yuan Shikai and the Boxer Uprising

At this point the Qing Dynasty general Yuan Shikai, who would eventually work to overthrow the dynasty and try to make himself a new emperor, was dispatched from Beijing to become a new Governor of Shandong. In order to deprive Germany of any pretext for sending its troops into Shandong, Yuan Shikai suppressed the unrest and restored order. As a result, when the new confrontation occurred, the Shandong Railway Company asked Yuan Shikai for military support, and he immediately sent 300 soldiers to protect railway construction. By the end of February 1900, there were 1000 Chinese soldiers guarding the construction site (Schrecker 1971, p. 114).

Meanwhile, Yuan Shikai decided to establish detailed regulations with the company in order to restrain the Germans and recover some autonomy (Wang and Wang 1987, p. 2). At the end of February 1900 he invited Hildebrand to Jinan to negotiate the terms, asking Vice General Yin Chang, who once had studied in Germany, to attend the negotiations. The negotiations were heated and over more than 20 days the drafts were revised several times (Chinese Academy of Social Sciences and the First Historical Archives of China 1983, pp. 171–172). On March 21, 1900, China and Germany signed the *Jiaoji Railway Regulations*, which contained detailed rules for land transactions, railway construction, and protection, thus normalizing railway company operations and straightening out the relationship between the company and local government. The result, however, was probably more beneficial to construction than to the Shandong population. In April 1900, villagers tried again to hinder the railway construction in the Haoli area of Gaomi and the disputes were settled relatively fast by both parties, using the *Jiaoji Railway Regulations* (Chinese Academy of Social Sciences and the First Historical Archives of China 1983, p. 248).

A third confrontation took place just prior to what is known in the West as the Boxer Uprising of 1900–1901. Members of the *Dadaohui* (predecesors of the *Yihetuan*, or Militia United in Righteousness, known in English as the Boxers) killed two German missionaries in Jüye, Shandong, in November 1897, providing Germany an excuse to occupy Jiaozhou Bay. Later, due to suppression by Yuan Shikai, the Boxers in Shandong moved northward in spring 1900. In June, they spread to Beijing, where they set fire to churches, attacked religious believers, and destroyed almost everything connected to the foreign world. On June 20, German minister Klemens von Ketteler, as a representative for all nations, went to Zong-li Ya-men asking for protection, and was killed halfway there by Qing soldiers, which then incurred military invasion by the Eight-Power Allied Forces. The next day, China's government declared war against Britain, the United States, France, Germany, Italy, Japan, Russia, Spain, Belgium, Holland, and Austria.

At the same time, villagers in Weixian and Gaomi secretly organized and invited leaders of the Boxers to teach them martial and magic arts (Mühlhahn 2005, p. 143). At the end of June, unrest arose from the Jiao River to Weixian, and in August large-scale confrontations burst out of the region of Jiaozhou. Members of the Boxers robbed railway engineers and attacked German residences. Not only were foreigners attacked, but also Chinese railway workers (Wang 2012, p. 131).

To protect their safety, Yuan Shikai asked foreigners to evacuate from the interior and promised to protect any property they left behind (Schrecker 1971, p. 132). Meanwhile, at request of the railway company, Jaeschke sent troops to guard the area of Jiaozhou and asked the company to resume the Qingdao-Jiaozhou line construction under military protection (Schmidt 1976, pp. 82–83). In October 1900, Jaeschke and Yuan Shikai made an agreement that the construction within 50 km of the railway (25 km on either side) should be protected by the governor of Jiaozhou, while the construction outside the area should be protected by Chinese authorities. Jaeschke then sent 200 soldiers respectively to Gaomi and Jiaozhou to ensure restoration of construction (Wang 2012, pp. 131–132). German troops clashed with villagers southwest and northeast of Gaomi, killing around 450 villagers (Mühlhahn 2005, pp. 146–147). In winter 1900, the overall tensions in Shandong eased off. In early 1901, the Shandong government signed an agreement with the Shandong Railway Company and Shandong Mining Company that the government should compensate the losses of both companies due to the unrest with a sum of 120,000 taels (Schmidt 1976, p. 84). All costs were finally apportioned to peasants in Gaomi.

17.5 Sources of Conflict

The immediate cause of all three conflicts mentioned above were the brutal behaviors of the Germans. However, if we try to explore the sources in depth, the conflicts could be attributed to two categories, one cultural, namely, *fengshui* and tomb culture, and the other personal interest, involving land property rights and farmland drainage.

With regard to *fengshui* and tomb culture: According to the *Modern Chinese Dictionary*, *fengshui* refers to the geographical situation of a house site or tomb. According to *fengshui* theory, this situating may influence the future of the family and their offspring. At the beginning of railway construction in China, one of the reasons brought up by those who were against it was that the railways would do harm to *fengshui* and, once it was destroyed, disaster would follow. It was believed that the laying of tracks, the noise of trains, and the black smoke would disturb the gods and have unfavorable impacts on tombs, farmland, and houses. Particularly, the position of tombs was never taken into consideration in the planning of the railway, which was believed to offend the ancestors. A German who lived in China for 20 years in the late nineteenth century wrote,

> The strongest link in the chain of superstition is called *fengshui* which literally means wind and water or influence of wind and water. Everyone is affected by it, and it must be taken as one of the most dangerous stumbling blocks as it hinders free mind and the civilization and progress of China…. *Fengshui* forbids the introduction of new things, for the well-being of the area will be severely damaged, causing flood, plague, drought and similar misfortunes. (Biener 2001, pp. 42–43)

At first, the Shandong Railway Company paid no attention to *fengshui*. The position of tombs was not taken into consideration in the layout of the railway lines and tombs were even destroyed, which provoked the villagers. The *Jiaoji Railway Regulations* signed in 1900 specified that the railway should make a detour around tombs so that they would not be destroyed. If there were no alternatives, the railway company should ask local officials to notify the owners 2 months in advance so they could rebuild the tombs elsewhere and suffer no losses in terms of money. The compensation to be paid by the railway company for relocating tombs was specified in the land contract, generally, marks (Dost and Hartwig 1981, p. 77) or 2–3 dollars for one tomb (Wang 2012, p. 134).

In practice, it seemed feasible to solve the problem of moving tombs with money. According to the Shandong Railway Company, "once it is proved that there is actual benefit, *fengshui*, namely the soul of wind and water, would not be any reason for opposition; once the relatives were paid a small fixed amount for moving tombs, the honor to the dead was no longer an obstacle" (Wang 2012, p. 134). As for the Shandong Railway Company, the tomb issue did not pose a serious hindrance, and *fengshui* was no longer considered a big deal to railway construction, especially after the Boxer movement.

With regard to land property rights: In China, land was divided into numerous pieces and property rights were complicated, which gave rise to difficulties for the Shandong Railway Company in making land purchases.

> By Chinese laws and customs, it is hard to determine whether somebody has the right to dominate a piece of land, to sign a contract for the land and to accept the amount paid for it. Land contracts and land registration books were few, which would definitely cause many problems. The individual right to purchase land is contradictory to the right of chief property right owners and secondary property right owners as well as those whose property right is hard to determine rationally or not; furthermore, it is contradictory to the requests and instructions from the family, clan, town, and guild. (Wang 2012, p. 135)

Because the railway company found it hard to negotiate with every land owner about land purchases, the company took a simple approach: it signed a land purchase contract for the whole county with the magistrate and representatives of the gentries of each county, which stipulated the average price for each *mu* (about 0.0667 ha) of land and a fixed amount of compensation for moving tombs and loss of farmland. The average price of land consisted of two parts, the value of the land and a reward paid to local officials. In Gaomi County, for example, the agreed price for each *mu* of land was 37,000 copper coins, among which 32,000 were land price and 5000 were awards to the magistrate and his escort. When measuring land, the railway personnel and the magistrate carried out the work together. Then the company gave the magistrate the payment terms and arranged the place for payment. After the company paid the magistrate the amount for the land, the latter issued a receipt and land contract to the former (Wang 2012, pp. 135–136). Then the magistrate called the village leaders together, talked to them patiently, and handed out the amount for land, as well as compensation for moving tombs and trees. The land contract was guaranteed by the village leaders and issued by the magistrate (Yuan et al. 1928, p. 24). In May 1900, the railway company signed land contracts with Jiaozhou, Jimo, Gaomi, Changyi, Anqiu, and Weixian respectively (Wang 2012, p. 136).

However, in practice the railway company sometimes started construction before the land purchase was complete and the amount paid to peasants was usually lower than the actual value. The company translators also cheated and blackmailed villagers for money by threatening that the railway would otherwise pass through their houses or tombs (Shandong Lishi Xuehui 1961, p. 89). In addition, the railway workers hired by the company mostly came from other northern provinces, earned more money than local people, often had conflicts with the community, and seldom were punished for their illegal deeds while under the protection of the company (Mühlhahn 2005, p. 133). The behavior of the railway personnel severely violated the interests of local people so that conflicts were inevitable.

The local farmland drainage system was also destroyed during railway construction, which was verified by later events. In the summer 1902, severe flooding followed 4 days of constant rain in Gaomi. Countless houses were destroyed, large tracts of farmland flooded, and many people became homeless. In August 1902, a

German naval engineer was sent to the area by the Jiaozhou governor to inspect, and later asserted in a secret report that the flooding was undoubtedly caused by the railway construction (Mühlhahn 2005, p. 149).

17.6 Construction of Stations and Roads

The Jiaoji railway was the first in Shandong and it took some time for people to accept it. Recall that the first railway in China, constructed in 1876–1877 between Shanghai and Wusong, was so socially disruptive that the Qing government felt forced to purchase it from its British owners; after taking possession, the Chinese government then tore it up. That such a negative reaction was not limited to China has been documented by Wolfgang Schivelbusch (2014), revealing the forgotten cultural dislocation experience by railway travelers even in Europe during the nineteenth century.

Extending the incomprehension and fear of railway technology, several violent conflicts during the initial period of Jiaoji construction reinforced public antipathy. As one account dramatically depicted the people's first sight of a traveling train:

> On the day the railway was open to traffic, the Chinese people standing along the railway embankment looked at the splendid new train in amazement, especially the fuel compartment ejecting fire on the front. When the train traveled toward them, they were freaked out and ran away from the rumbling and giant monster. (Biener 2001, p. 172)

Due to popular fear, at the beginning of construction many stations were kept outside of the city walls. People did not want the "fire dragon" to get close (Biener 2001, p. 172). As construction advanced, the situation gradually changed. In 1906, Hildebrand wrote in a report on railway stations:

> When the line was first located, it was not in every place that stations could be set near to a position with dense population and busy traffic for the development of the railway. Among the reasons, one was a geographic difficulty and another was opposition at the beginning of construction by those who did not want to see the railway passing through tombs and temples. But after the first section of the Qingdao-Jiaozhou line was put into use in April of 1901, the Chinese soon realized the advantages of modern means of transport and changed their minds for the latter half of railway construction. Jiaozhou station and Weixian station were almost 1km away from the city walls, while the later constructed Zhoucun and Jinan stations were as close to the commercial center as the terrain allowed. On deciding the position of Jinan station, Zhou Fu, the wise governor of Shandong, had the foresight to ask that the planned east and west stations be moved closer to the city and one more station be added at the northwest gate. Similar situations can be seen in Germany, where some cities today suffer from being long distances from railway stations, because when railways were constructed, municipal authorities would not allow railway companies to situate stations in the heart of the cities. (Wang 2012, p. 145)

Besides a geographic location close to city center, railway stations should be near roads. Road construction as part of infrastructure development was rarely done by the Chinese government. Apart from official post roads, other roads were generally in poor condition and unpaved, which made them hard to use on rainy days. In order to abate the unfavorable influence of bad weather on railway transportation and make it easier for people to get to the stations even on rainy days, the Shandong Railway Company decided to build roads leading to stations in some major cities and counties, such as Weixian and Qingzhou.

However, road construction was not a typical function of the Shandong Railway Company and it had to negotiate with local governments. Long before the railway was open to traffic in Weixian in June 1902, the company had proposed to the magistrate of Weixian the construction of a road from the railway station to the county capital, which local gentries and businesses supported. The company thought that the road could be built before the railway was open in Weixian. However, it was not until November of that year that the Weixian magistrate agreed with the proposal, though there was no money to build the road. The magistrate had to report to the Shandong governor, who, at the plea of the railway company, approved of the road construction, with expenses to be born by local authorities. Afterward, the company and the Weixian county government held talks to which the governor sent a representative. During the negotiations, the Weixian magistrate initially refused to approve the project, saying that the literati would object because it might destroy *fengshui*. Representatives of the railway company argued that more examinees had passed the imperial examination that year than ever before, which the representatives of the government had to acknowledge, so that the railway must have made *fengshui* better, not worse.

Finally, the road connecting the Weixian county capital and the railway station was constructed. C. Fink, the editor of *Der Ostasiatischer Lloyd* from Shanghai, once inspected the Jiaoji railway and remarked that "this might be the best road in China. The 20 m wide embankment led straight to the main city gate from the railway and the whole road surface was paved with square granite" (Wang 2012, p. 146). The railway company also built roads leading to railway stations in Qingzhou and Zhoucun with expenses born by local governments. The roads from Jinan to Jinan East and West Stations were under the charge of the Shandong governor.

17.7 Conclusion

Modern Chinese society was in a slow transition; fundamental aspects such as the political system, social structure, laws, and ownership relationships remained in traditional status for a long period. People had a strong aversion to new technologies, and modern technology transfer to China was often accompanied by the expansion of Western powers (even technology transfers initiated by China were unavoidably associated with the squeezing, cheating, and exploitation of Western powers). All of these factors influenced the complexity and hardship of modern technology transfer to China.

The railway technology transfer, in this case, happened in the context of colonialism, and was imposed on recipients by those transferring the technology. The Jiaoji Railway construction was part of a Sino-German treaty imposed by Germany.

However, colonialism was never a unilateral activity in which the colonialist powers could impose just any arbitrary transformation or influence on traditional society. Rather, it consisted of interactions between the two societies, insofar as members of each society found ways to express their opinions and take action (Mühlhahn 2005, p. 490). The conflicts and adaptations during the construction of the railway were the result of interactions between both parties to the technology transfer, even when one was clearly more powerful than the other.

Society, culture, politics, and diplomacy all influenced the Jiaoji Railway construction process. To guarantee construction, the Shandong Railway Company took all measures at its disposal to eliminate obstacles. During the initial construction period, the company had several severe conflicts with the local people; even the German minister Ketteler admitted that "the unrest was caused by brutal behavior during the railway construction, while other countries had constructed several railways in China over the years without being disturbed" (Mühlhahn 2005, p. 133) . When contradiction and conflicts arose, the Germans did not try to solve them in a productive manner, or conform to the reasonable requirements of the local people. Instead, they used cruel military suppression, which clearly reflected their colonialist mentality. It was not until Yuan Shikai took advantage of the suspension of railway construction due to unrest and negotiated the *Jiaoji Railway Regulations* that company behavior was normalized and the relationship between the company and the government settled down.

The sources of the conflicts during construction can be attributed to cultural factors and economic concerns. The unique *fengshui*, tomb culture and complicated property rights created difficulties for initial land purchases. Besides cooperation with local governments, the railway company sought assistance from gentries. In traditional Chinese four-class society (gentries, peasants, workers, and merchants), gentries had the highest status. Before general education, many relied on the gentried or literate class of Chinese society. This class formed the elite in local society, having better education and capabilities than the general public, while also being more suitable to guide the general public than bureaucrats, because they were closer to the public in terms of social status and relationship (Fairbank and Liu 2006, p. 289). The literate gentry enjoyed extensive political influence locally and served as village spokespeople, who could pressure authorities on matters concerning the local community. The society was usually stable and strictly controlled by elite families (Mühlhahn 2005, p. 53). The special status of gentries in Chinese society caused the Germans to select them to cooperate with.

After Yuan Shikai was appointed governor of Shandong, policies with regard to Germany changed considerably, from rejection to negotiation. Now that the railway was an established fact, the pragmatic option was to manage construction as smoothly as possible and take advantage of the railway. As people came to realize the benefits of the railway, their opposition toward it became weaker, and railway stations were subsequently placed closer to commercial centers than had been done during the initial period. Roads leading to railway stations in major cities and counties were built by the railway company under with support from the Shandong government. All these factors reflected people's active adaptations to the changes brought by the railway.

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Part IV
Engineering, Ethics, and Society

Chapter 18
Between Optimism and Despair: Engineering, Anthropology, and Development in the Twenty-First Century

Rita ARMSTRONG

Abstract There are differences between the typical optimism of engineers regarding the benefits of development and the more skeptical views that have become common among anthropologists during the last 50 years. It is tempting to reduce these differences to intellectual stereotypes: engineers solve problems while anthropologists pose questions, engineers create while anthropologists critique. However, more critical attitudes have begun to emerge among engineers and engineering educators in this field, and not all anthropologists who work in development see reflexivity as a postmodern condition of apathy. Most important is to acknowledge power differentials between development agencies and communities and how the institutional cultures within large aid agencies have the power to determine whether projects fail or succeed according to their own, often arbitrary, criteria. To illustrate how issues of power differentials are often more important than technological development, I briefly consider case studies of attempts to introduce newly designed cook stoves (in Sri Lanka and Bangladesh) and dendro power (in Sri Lanka). Shared insights from engineers and anthropologists, who pay critical attention to the practice of development and the context in which it operates, suggest that we should focus on interdisciplinary strengths and not differences when confronting impoverishment that results from deep seated structures of inequality.

18.1 Introduction

In 1960 Walt W. Rostow, the American economics professor who had served as a political adviser to President Dwight D. Eisenhower and who would become adviser to Presidents John F. Kennedy and Lyndon Johnson, published *The Stages of Economic Growth: A Non-Communist Manifesto*. For Rostow (1960) and many in

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the West, the idea of capitalist driven techno-economic development was seen as alternative to the Marxist ideology of class struggle. In the 1990s, after the end of the Cold War, the idea of development began to receive almost unquestioned support among economists and politicians in both developed and developing countries. Unremarkably, the idea has also been influential among engineers while, remarkably, it has been increasingly questioned by anthropologists. What follows is a brief reflection on what deserves to be an extended dialogue between engineers and anthropologists regarding the question of development.

18.2 Engineering, Anthropology and Development

Engineers everywhere are urged to become more innovative in using their knowledge and skills to alleviate poverty, to mitigate the impact of climate change, and to assist in responses to natural disasters. These exhortations occur at the global level (UNESCO 2010), the national level (e.g., CEES 2008), and at the local level on university campuses (Nieusma and Riley 2010, pp. 29–30). Increasingly, these types of activities are positioned within a framework of humanitarian engineering and received widespread support within mainstream engineering. In Australia, for example, 2011 was declared to be the "Year of Humanitarian Engineering" (Engineers Australia 2015) and this initiative was supported by Engineers Australia, Registered Engineers for Disaster Relief (RedR), and Engineers Without Borders (EWB 2015). Carl Mitcham and David Muñoz (2010) have written about the qualities of the humanitarian engineer and the IEEE held a Global Humanitarian Technology Conference in 2012.

Almost without exception, the practice and ethics of humanitarian engineering is linked to development, that is, development as a means to alleviate poverty. Mitcham and Muñoz (2010) discuss the qualities of humanitarian engineering in a global sense as a way of changing the values that inspire all types of engineering practice, but say there should be a particular focus on the "active compassion" that is "directed toward the needs of the poor, powerless, or otherwise marginalized persons" (p. 59). Non- government organizations such as EWB most often choose their project partners as those living in countries other than Australia. They partner with local NGOs that have identified specific needs of the rural poor in countries such as Cambodia, India, and Vietnam, and many universities in Australia and New Zealand participate in the annual EWB Challenge whereby students can design projects that address those needs. EWB also works with Aboriginal communities in Australia and in 2010 devised their National Challenge in partnership with the Kooma Aboriginal community in rural Queensland (EWB 2015). Overall, there is an increasing sense of optimism and hope that engineers can and should use their knowledge to address the needs of impoverished and marginalized communities.

Anthropologists, by contrast, are increasingly pessimistic, cynical, or resigned with regard to the values and benefits of development, whether development arrives in the form of state-sanctioned projects (from dams and mines to palm oil plantations) or NGO projects aimed at addressing literacy, improving sanitation, or setting up alternative means of subsistence. The beginnings of disenchantment were felt when Ivan Illich told volunteer aid workers to go home (Illich 1968) and have continued almost 50 years later with Henrietta Moore (2015) talking, albeit in more measured tones, about “The End of Development”.

The historical unfolding of criticism in the intervening years is well known and I have presented that history to anthropology and engineering undergraduate students on a few occasions. It goes something like this: scholars from postcolonial societies questioned the assumptions that underlie the distinction between “developed” and “undeveloped” in the early 1990s. Most well-known are Sachs (1992), Gustavo Esteva (1992) and Arturo Escobar (1995) who queried why national development should be equated with particular forms of economic growth, and why it was assumed that growth would reduce inequity. These views were reinforced by work that demonstrated how state-sanctioned modernization projects did not, in fact, increase prosperity and well-being in the underdeveloped world (Chang and Grabel 2004). While some indicators improved, such as infant mortality and literacy, the gap between the privileged and the poor widened (Stewart 2006, p. 14). Furthermore, aid projects (co-funded by states and agencies such as the World Bank) came under scrutiny from scholars such as James Ferguson (1985, 1990) who questioned the apolitical nature of those projects whose failure, he argued, could be attributed to a blind disregard for underlying political and cultural realities of social life.

For those working in the aid industry, the questions posed by post-development theorists made sense. Is not aid a new form of colonialism? Is not the transfer of knowledge and technology yet another exercise of power by the old colonial powers? At the same time, many were unwilling to reject the whole project, no matter how it was construed. Furthermore, it was argued, not all development is inevitably a route to modernization (Pieterse 2000), and not all indigenous peoples or rural peasants wish to reject modernity or necessarily purse an alternative economic model (Kiely 1999).

For those who focused on addressing local needs in a more collaborative and participatory way, other obstacles emerged. First, as Mosse points out, many international aid policies continue to advocate free trade as a means to poverty reduction (Mosse 2005b, p. 5) despite evidence that “regulation of and active intervention in markets by government, at national and international levels, is generally found to be welfare-improving and development-enhancing” (Storm and Mohan Rao 2004, p. 572). An example of such projects might include plans to grow cash crops on small holdings. Second, and these views come from those who work with the rural poor, obstacles may arise within aid agencies depending on how they are funded. Those who are keen to practice an alternative form of development—who do not assume that communities are passive victims receiving the superior technology and knowledge offered by experts, and who take a relational view of poverty—often find the road to failure or success is constrained by bureaucratic demands. These may include an audit culture which is driven by a cost-benefit framework (Mosse 2005a) or a requirement to “pursue the nominated project outputs, like numbers of latrines, despite these not necessarily being prioritized by communities” (McGregor 2007, p. 162).

There are multiple purposes in delivering this history to undergraduate students, all aiming to provide them with tools with which to think about development. We want engineering and anthropology students to be able to:

- Deconstruct common held ideas about developed/undeveloped, North/South
- Distinguish between different types of development—development as modernization and growth, development that meets local needs and aspiration (and are those necessarily different?)
- Be aware of how NGOs are funded and whether their budgets depend on achieving outcomes determined by management personnel sitting in offices in donor countries.

Inevitably, students are often dissatisfied, disgruntled, and in some cases, depressed (Djohari 2011) after listening to and debating what goes wrong in the development field.

Is there life beyond deconstruction and criticism? Can we find some space between unreflexive optimism and nihilistic pessimism that offers pragmatic guidance in how to go about understanding and addressing persistent and enduring poverty and marginalization? Katy Gardner and David Lewis point out that anthropologists need to "move beyond deconstruction" (Gardener and Lewis 1996, p. 157) but take the critical insights with them to create a more informed practice. Here I will look at some of the shared insights generated by anthropologists, aid workers, and engineers who have worked on the delivery of appropriate technology in projects funded by established aid agencies in areas that are prioritized as being in need. First, however, I want to look briefly at the concept and categorization of poverty.

18.3 Poverty, Power, and Impoverishment

One of the key outcomes of post-development thinking was to question the nature of poverty (Escobar 1995, pp. 20–24). Although there is greater institutional awareness of how difficult it is to define and characterize poverty, attention is still focused on describing rather than explaining specific conditions of impoverishment. David Mosse, an anthropologist who worked in India for many years, describes persistent or durable poverty as a consequence of historically developed economic and political relations, and also as a result of enduring social categorization and cultural identity that renders inequality and exploitation socially acceptable (Mosse 2010, p. 1157). He sees persistent poverty as "the consequence of the exclusionary and expropriating aspects of the long- term processes of capitalist transformation" but which is reproduced by "social processes which have their own logic" (Mosse 2010, p. 1156).

My own fieldwork was carried out in a longhouse settlement in Sarawak, East Malaysia. It is a remote region, and thus protected from the processes of capitalist transformation evident in so much of lowland South East Asia (Armstrong 1991). While I was there in the late 1980s, communities subsisted on hill rice agriculture supplemented by fishing and hunting. In the community where I lived, intermittent electricity was supplied when government funds were available, but only to the headman's longhouse. When the electricity came on, everyone crowded into his longhouse apartment to watch B grade Chinese action films or music videos of Michael Jackson.

One of the conditions of that fieldwork was to write a report about the potential impact of a hydroelectric scheme on another longhouse settlement about two hours downriver from where I lived (Armstrong 1987). I was asked to describe social organization, to gauge prosperity through income levels, and to discover whether any ancient burial sites would be inundated by the reservoir. In order to determine 'income', I was asked to itemize all household goods (such as outboard motors, chain saws, sewing machines, portable cupboards, tools, canoes, etc.), and to value subsistence, primarily how much rice each household produced, but also how much wood was used to cook food.

It was, in effect, an audit, but none of it made a great deal of sense. Many people owned outboard motors or chainsaws, for example, bought when the men had gone away to work as wage laborers, but this technology often sat idle on the longhouse verandah because their owners had no cash with which to buy petrol. Naturally, I was asked by the local community to translate and explain the survey questions that were written in English, and the subsequent discussion was about the degree to which responses should or could be inflated. Was it better to lower the harvest yield in order to be seen as poor or to inflate it to increase compensation? I did not know the answers to these questions. I wrote down whatever responses each household dictated to me.

The other nonsensical part of this survey was that both this community and the community with which I lived, the Kenyah Badeng, did not have a word for being poor. Ideas about livelihood were based on sufficiency and insufficiency and the ability to meet household needs (Armstrong 1998). Knowing how much rice each household produced was not equivalent to knowing whether that amount was enough to feed the extended family, to sell for cash so that children could go to secondary school, to repay a rice debt from a previous year, and more.

More importantly, the Kenyah Badeng did not feel poor because even if they did not produce enough rice to last the year there were opportunities to remedy that by borrowing from kin, by harvesting for other people in return for rice, and by eating less rice and more cassava or sago. They also wished to increase the opportunities whereby those needs could be satisfied. The concept of development (*kemajuaan* in Malay) was something to which they aspired; having a local primary school, regular visits from the flying doctor services, receiving cocoa or pepper seeds from the Department of Agriculture, having a permanent supply of electricity—all these were desirable types of *kemajuaan*. The free cocoa and pepper seeds that were funded in part by the World Bank (Ngidang 1995, p. 306) were not, however, used to supplant rice agriculture as envisaged by the state. These plots of cash crops were seen, rather like Ferguson's cattle (1985), as assets or an additional source of income to bolster their existing livelihood.

While being autonomous in some respects, longhouse people were powerless in others. Being citizens with customary rights over land did not entitle them to have any say about the appropriation of their land for logging, nor did it give them any say about the construction of a dam that would inundate 15 longhouse settlements and transform their lives from one of independent subsistence to one dependent on the growth of cash crops, whose prices were in turn dependent on the global market (WCD 1999). The dam, unlike logging, was also represented as *kemajuaan*. Hydroelectricity would bring prosperity to all people in Sarawak the government claimed; furthermore, the resettled communities could grow cash crops and live in modern longhouses with electricity and running water. The ethnographic reports that I and others wrote were ultimately ignored by the construction consortium in receipt of tender to build the dam (Rousseau 1994).

This vignette is a story in reverse about how power and impoverishment are linked. I say "in reverse" because the Kenyah Badeng were not the objects of attention from any NGO aid agencies, despite being classified as rural poor by the state and national governments (King 1990). The Kenyah Badeng also did not live within the boundaries of the proposed reservoir, and so avoided having to resettle and live with an allocated two hectares of land in a new area. They prophesized that anyone who was resettled "would become coolies on palm oil plantations". A "coolie" is a pejorative term for unskilled labor that were imported by colonial states (the British and the Dutch) to work on plantations. Critical insights do not have to come from academics or activists; local people are well aware of the consequences of not controlling the means of production.

These are crucial issues. Rural people lack political power to influence major policy decisions that affect their livelihoods: very few people openly resisted the dam project, being too fearful to do so. Furthermore, they are unlikely to gainsay any development project that comes their way, even if the state-sanctioned goals (which in this case meant abandoning subsistence agriculture in favor of planting cash crops) did not match their own aspirations.

18.4 Addressing Impoverishment: Critical Insights from Appropriate Technology

Most engineers who work in the development field argue that you can address the basic needs of impoverished communities with some relatively simple understanding of the local context. It is generally assumed that the delivery of appropriate technology, such as solar panels, composting toilets, or micro-hydro schemes, is inherently positive; with the right training and capacity building, these projects will be successful and offer a way out of poverty. There are nevertheless increasing numbers of engineering educators who disagree with this model. The work of Caroline Baillie (2006), Baillie and George Catalano (2009), Donna Riley (2008), Catalano (2007), and Mitcham (2014)—to cite a few examples—argue that technology is not value free and question what engineering development organizations are trying to achieve. Is development an outcome that fits the goals set by international or national funding bodies, or an outcome that addresses or at least acknowledges the power imbalance that lies at the heart of the kind of impoverishment discussed above?

In response to such questions, consider the proposed introduction of two kinds of appropriate technology: improved cook stoves and dendro power (a small scale, wood based form of energy production). The narratives about both projects shed light on the framework and motivations of NGOs (particularly those funded by other agencies) and how the best motivated projects can be complicated by policy frameworks.

Emma Crewe is an anthropologist who used to work in the Intermediate Technology Development Group (ITDG) founded by E. F. Schumacher and now known as Practical Action (Practical Action 2014). Elizabeth Harrison is another anthropologist who has worked with the Food and Agriculture Organization (FAO) on the delivery of fish farms to Africa. In the introduction to their book *Whose Development? An Ethnography of Aid*, they recount a story about the successful delivery of improved stove technology to Bangladesh. Briefly, the traditional method of using rocks to support cooking pots above a wood fire has been widely criticized for generating too much smoke in small huts without chimneys (causing respiratory infections), for using too much wood, and also for diverting labor—women and children generally collect firewood—from more productive (money-making) activities. Improved cook stove technology would reduce deforestation, it is argued, while giving women more autonomy over the use of their time. Here is an edited version of that story:

> Jim, a young British energy expert, has been asked for advice about cooking stoves in rural Sri Lanka. During a visit to a tea plantation, he walks into a kitchen in the house of one of the female workers. He notices that smoke from the chimney is being directed up into a hood. This is unusual and when he discovers that the hood is the woman's own invention, he congratulates her, and sketches the design. He then writes a funding proposal to the World Health Organization using what he describes as 'indigenous technology' to solve the indoor smoke problem. Because WHO has identified Bangladesh as a priority area, Jim pilots the scheme there instead of Sri Lanka. The local people are not receptive and it is assumed this is because of cultural reasons. New electric stoves are developed and are sold to 10,000 people who like them because they consume less fuel. People who cannot afford the new stoves, quite a large number, are of course left out. Nonetheless the donor agency is pleased that the problem of air pollution has been solved for 10,000 people and can write a final report that outcomes have been achieved. "Meanwhile the originator of the hood, the tea worker in Sri Lanka, has designed an improved version made of stronger materials which has been widely copied in her area without the help of any aid agency." (Crewe and Harrison 1998, pp. 3–4)

This anecdote certainly muddies the water around what is deemed to be a successful project, and we have to ask ourselves: successful for whom? When cook stove projects are deemed to be failures, the project developer's blame lack of proper training or cultural barriers, but Crewe and Harrison provide examples where this reasoning is specious: very often women do not have time to cut the fuel into small pieces (which is required for many "improved" cook stoves); or they do not want the chimney if mosquitoes are abundant (Crewe and Harrison 1998, pp. 106–107).

However, more significant than the challenges associated with this new technology are the assumptions that underlie its introduction. The Intermediate Technology staff did not question the "potential positive effect of technology itself" (Crewe and Harrison 1998, p. 33). There is an implicit and unquestioned assumption that appropriate technology enhances people's lives by improving their health *and* their ability to earn money, "so, piecing together the broader picture, the implication is that poverty is caused by technological gaps and solved primarily by technological improvements" (Crewe and Harrison 1998, p. 33). Improved cook stoves should save resources and time, and this time will be spent in some kind of positive (i.e., entrepreneurial) activity. But what if this is not a priority? What if the time is spent making social contacts or resting (Crewe and Harrison 1998, p. 128)? Is the project still a success? Both authors wonder why, when most ITDG staff recognize that poverty is caused by economic and political inequality, that their projects do not reflect those insights. "Perhaps it is because social relationships are much harder to change" they conclude (Crewe and Harrison 1998, p. 33).

The second story concerns another type of small-scale energy technology: dendro power. Dendro power is a form of wood-fueled electricity generation and has been promoted by the Energy Forum (2015a) as a source of sustainable energy for off-grid villages in rural Sri Lanka. The Energy Forum is a Sri Lankan NGO that was initially an Intermediate Technology Development Group project, but became independent in 1999 (Energy Forum 2015b). It promotes a range of renewable energy technologies, with an overall goal of addressing social justice issues by making energy available to all sectors of the rural poor. The dendro option was popular with the state energy sector, as well as other NGOs, because the energy source (wood) is available locally and can be grown on small holdings, and the cost of setting up a plant was relatively low (the entire project cost was $40,000) (Nieusma and Riley 2010, p. 44).

The following account is based on Dean Nieusma's experience of working with the organization on a dendro project for a rural village. This particular project, however, was never implemented. After several months of planning and community engagement, the project was terminated because, despite advice to the contrary, the national grid was extended to the focus village, thus making electrification redundant. The following is a description of Energy Forum's approach to implementing dendro technology (summarized below from Nieusma and Riley 2010, pp. 42–51). It sheds light on why, despite using what a "participatory, bottom-up approach", the obstacles to achieving social justice lie in areas outside the engagement process: specifically, the powerful interests of the state and the funding agencies balanced against the actual needs of the communities themselves.

Energy Forum explicitly recognized that correct technical implementation alone would not guarantee project success. While setting out programs to maintain technological feasibility (plant maintenance, education about why types of appliances could be used) they envisaged productive outcomes which, they believed, came from electrification. This was seen as an integrated approach to electrification. The Energy Forum sought to ensure that the community was prepared for the project by visiting the village many times; the team included four engineers, a sociologist, and two community organizers, all of whom spoke Sinhalese. This team stressed that the project was an experiment, they were honest about the commitment required to manage the plant, and that a 2 year monitoring and evaluation phase was planned before plant ownership was transferred to the community. Although the practice of engagement was extensive and it was planned that ownership would pass to the community at some stage, the project was controlled by Energy Forum until that time.

Furthermore, despite being aware of, and attending to, the importance of community engagement, "it was the technology … that was featured in the group's external communications … especially to international funding agencies" (Nieusma and Riley 2010, p. 47). The overarching interest in the success of dendro technology in rural Sri Lanka also impacted on Energy Forum's activities. Other NGOs and private companies were keen to become experts in dendro technology. The incentive to become the "authority" in this field, together with the substantial financial investment in the project, created pressure to prove the group's engineering success in this.

In Nieusma and Riley's view, the Energy Forum exemplified "a relatively sophisticated and highly reflective approach to development," but ultimately the community was compelled to accept projects "motivated by external groups with a distinct set of interests" (Nieusma and Riley 2010, pp. 49–50). Dendro power attracted a lot of enthusiastic attention from the state energy sector and development agencies, not just because it was a low cost and sustainable form of energy, but because it was seen as way of "uplifting (the) standard of living" (Energy Forum 2015b) by using electrification as a means of pursuing productive activities that would otherwise not be possible. Here again is the potential for success or failure to be judged in terms set by the donor agency. What if people, to put it facetiously, want to watch B grade action movies or music videos? More troubling are the assumptions that informed the project's approach. As Nieusma and Riley points out: "too many community members were reluctant to share their thoughts or contradict the project sponsors … the team went to the village knowing that electricity 'was needed' making it difficult to hear what the villagers were saying about, for instance, their problems with alcohol or joblessness" (Nieusma and Riley 2010, p. 50).

18.5 In Place of a Conclusion: Sharing Insights

In both narratives, external interests drive development and implementation of appropriate technologies to the rural poor. Nieusma and Riley's observations that the Sri Lankan villagers were not in a position to turn aid projects away, even when they do not align with their most pressing problems, is crucial. If we understand poverty in these terms, both as a consequence of historical inequities as well as cultural hierarchies, we will better understand why the powerless are predisposed to be silent about any misalignment between their actual needs and project goals as determined by national or international agencies.

An antidote to the perils of deconstructing development may be found in using a different vocabulary and basing practice on a different set of questions. Too often the vocabulary of development is about deficiency or lack in terms of educational levels or capacity to manage projects that are not formulated by communities themselves.

Increasingly engineers agree with anthropologists that they must ask questions about power, culture, and inequality, not just to understand the communities they serve, but also to understand relationships between those who are offering knowledge, money, or technology to those deemed to require it (Crewe and Harrison 1998; Mosse 2005a).

Talking about "inequality" rather than "development" and directing our attention on relations of power and how these intersect with cultural hierarchies will take the focus away from development as an activity that happens in "other" places. For undergraduate anthropology and engineering students, development as aid work presents the "possibility of 'exotic', interesting work that is morally sanctioned" (Djohari 2011. p. 22), but we live in a world where conventional taxonomies no longer make sense. We can no longer assume that the old dichotomies—developed/undeveloped, rich/poor, sustainable/unsustainable—are anchored to or defined by the political geographies of the Global North and the Global South. The Global North, for example, seems to be moving ever southward (the suburbs of Athens to the business district of Luanda, Angola), while the Global South is moving northward and eastward, to China for example. For engineers and anthropologists, our shared critical insights about the practice of 'development' transcends these dichotomies and challenges the view of modernity that continues to shape the development paradigm, that is, as an "ideology of improvement through the accumulation of knowledge and technical skill" (Comaroff and Comaroff 2013, p.18).

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Chapter 19
"I Became an Engineer by Accident!": Engineering, Vocation, and Professional Values

Christelle DIDIER and Patrick SIMONNIN

Abstract Contrary to many other countries, in France, engineering education remains attractive. Paradoxically, French students do not seem to be motivated by the engineering profession and many graduates seem to have become engineers "by accident". The outcome of our research is that engineering students are "pushed" by an invisible parental and social pressure. The most successful ones end up in a very few prestigious schools, which are supposed to open the doors of the higher management positions in big private companies and public administration, the great majority in a school they have hardly heard about before the "concours", with little motivation for applied science, hardly any vocation for engineering. This work is at the crossroad of two developing approaches within the fields of educational sciences and sociology: the choice to study successful students belonging to the upper or upper middle class which are less investigated than lower classes, and the choice to adopt a qualitative approach, while most researches about orientation are based on wide quantitative surveys. Our aim is to contribute to a better understanding of the construction of the engineers' culture and ethos, through an analysis of the socialization process from the engineering students' point of view.

19.1 Introduction

Contrary to many other Western countries, in France engineering *education* remains quite attractive. But paradoxically, French students do not seem to be motivated to enter the *profession*, to work as engineers. In 2009, in a survey about the students' motivation to enroll in their studies, 19% of French male engineering students (and 10% of female) declared that they did not want to become an engineer, *versus* 4%

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of European students. More than 25% of French engineering students declared they believed they would not be working in the field of engineering 7 years after their graduation, *versus* – to take a contrasting case – 0% of German male and 6 % of German female students (Cdefi 2009).

In order to explain the gap we observe between a high appeal for engineering education in France and the surprisingly low interest for the profession itself, we have developed an original research program with the goal of understanding the reason why French engineering students have chosen this educational track. This question has implications for engineering ethics. Actually, the deeper question behind this is: "how can we expect engineers to take up the major challenges of development and sustainable development that face their profession, if the students are not interested in engineering?"

19.2 Context of the Study

One of our hypotheses is linked to the French system of higher education, highly structured by the distinction between the Universities and the *Grandes Ecoles* (schools of higher education), which we will first say a few word about. Higher education in France is historically divided between Universities and *Grandes École*s. Some curricula are given in both types of institutions, mainly Sciences and Technology and Business and Management; some curricula are given only in Universities, like Medicine, Law and Humanities. When a curriculum is given in both spheres, the *Grandes Ecoles* are usually said to provide a better (even the best) quality, because of the general level of the students (as a consequence of a stronger selection at the entrance), and because of the smaller size of the classes and of the institutions. In short, *Grandes Ecoles* appear to give more chances to their students to enter the 'elite' of the nation (Bouffartigue and Gadea 1997).

Someone wanting to study Engineering must enter one of the 240 Engineering *Grandes Ecoles,* among which 10 are considered as the greatest, the "top ten" (Baron 2010). More than two centuries ago, the first French engineering curricula were given outside of the university and until the end of the nineteenth century, only a handful of institutions had been training engineers in France. When their number increased, the profession organized. In 1934 a law was enacted to protect the title and to establish an accreditation body (Grelon 1984). During the twentieth century, many new schools were created. In addition, accredited curricula were started within the Universities' Faculty of sciences. Being the only programmes needing an accreditation from outside gives them a peculiar status. Although organized within the public university system, they are considered and called *Grandes Ecoles*. They belong to various networks dedicated to all *Grandes Ecoles,* or to engineering only *Grandes Ecoles*. In France, in most people's minds, the expression "engineering education" evokes the mythical world of the "*Grandes Ecoles*".

The "canonical (traditional, historical) model" of engineering education in France follows a "2 plus 3" years scheme organized in two separate types of institutions. Two years of selective 'Preparatory Classes' conclude with a selective competitive entrance exam. The more famous the schools, the more selective are the exams. Those 2 years are followed by 3 years in the engineering school, to earn the Engineer's degree, which is equivalent to a Master of Science in Engineering in the European System. Despite the Bologna process, the dominant model follows the "2 plus 3" scheme, instead of a 3-year Bachelor's degree plus a 2-year Master' degree.

The main alternative model to the 3-year program consists of 5-year continuous curricula, which is followed by one out of three students. Many private catholic engineering schools propose a program split into two periods: 2 years of "integrated preparatory class" which follow national programs, and 3 years which follow the school's program proper. Other types of 5-year continuous curricula have been proposed since the 1950s in the public-owned Institutes for Applied Science, which follow a German model, and since the 1970s a few Technological Universities follow the North American model. Finally, a dozen institutions gathered in the *Polytech'* network proposes engineering programs within the Faculties of Science of multidisciplinary Universities (Chatzis 2009).

19.3 Methodology

Our research project consists of a qualitative study based on one-to-one in-depth, semi- structured interviews. Our goal was to find out the reasons why students decided to enroll in an engineering school. The type of methodology we chose (a qualitative one based on a small sample) is often considered as appropriate, when the initial question of a research program begins with "Why?" or "How?". Here, our aim was to find out subtle relationships between the individuals' social and cultural context and the concrete choice they made. Qualitative approaches with interviews have been very rarely used in social science in France until recently to deal with educational choices, especially to deal with the choices of those who can choose (Blanchard and Cayouette-Remblière 2011).

We selected five engineering schools located in the north Region of France, which we found to be rather representative of the diversity of French engineering education. One was a 4-year curriculum with a very "atypical" model, at the mining school of Douai which is a publicly-owned school created in 1878. (There are four "minor" Mining schools, not to be confused with the prestigious Mining school of Paris. They recruit after 1 year of preparatory class for a 4-year curriculum. Their competitive exam is considered by many French students as just a training session at the end of their first year.) We also selected three catholic private 5-year curricula: HEI, created in 1885, which proposed various majors; ISEN, an electronic school created in 1956; and ISA, an agricultural engineering school created in 1963. The last school is a public school following the historical 'canonical model'. The *Ecole Centrale de Lille*, created in 1872, is considered as one of the best schools in the country, and the best in the northern part of the country.

The sample of students, selected by the academic dean of each school, is composed of volunteer ‘average’ students (not the brightest ones, but with a good probability to achieve their studies). There were a total of 17 students, 9 male and 8 female. Four were from the agricultural school, three from the electronics school, and two from HEI. These entered the project just after secondary High School. Four students joined the project after their first year of preparatory class when they entered the Mining School of Douai. The last four students joined the sample when they entered their 3-year program at the *Ecole Centrale*.

19.4 Analysis

We have distinguished two ideal types among the students.

(a) *First type: the determined and eager to become an engineer (5 students, plus 3)*

The “determined engineering students” are strongly committed to becoming engineers and want to practice this profession as soon as they can. They choose to enter an engineering school out of a true interest for the profession. Most of them joined a 5- year engineering school just after High school, and most of them come from middle class families. *Camille*, whose pharmacist father died when she was young, wants to work as an engineer in the food industry in order to design healthy food. *Matthieu,* whose father owns a farm, wants to work as a sales engineer in the field of agricultural business. Both of them chose the agricultural engineering school. *Guillaume,* also from a middle class family, has always been fond of nanotechnology and wants to manage technical projects in the field of electronics. He is not so much interested in the engineering title he will receive from ISEN, but rather the type of job engineering education leads to. *Aurélie*’s case is singular. She followed a very unusual track before entering *Centrale Lille*. Interested in civil engineering since High School, she was discouraged by her family to enter a *prepa* because of her older sister’s bad experience. She decided to study to become an engineer after 2 years of work experience under the responsibility of engineers as a Technical college student apprentice. She enrolled at university where she earned a Bachelors’ degree, took the national competitive exam dedicated to bachelor students, and she succeeded very well; she occupies one of the four desks opened to such students at *Centrale.*

Two Mining school students also belong to this group, although they entered a preparatory class without any desire to become engineers. For them, shortening the *prepa* after 1 year only to end up in “minor” mining school meant renouncing the chance not only to reach a top ten school, but also to enter one of the 200 other engineering schools reachable at the end of the second year of *prepa*. The decision not to continue in the second year may be a personal choice. *Marine* was eager to get out of *prepa* where she was pushed by the social pressure that weighs on all the good French pupils, especially when in an elitist high school. Having developed a true interest for civil engineering, she chose the mining school of Douai because of its majors.

Talented Chinese *Moxi* was pushed to go to *prepa* by her teachers, although her dream before arriving in France as a teenager was to become a novelist. Relieved to be out of the *prepa* system, she is now determined to work in the luxury goods industry. *Marion* was a very good pupil in high school. Daughter of an electrician and a social worker, she has always been very interested in maths and biology, but she thought university would only lead to teaching. Scared by the *prepa*, she chose a 5-year agricultural engineering school eager to earn her living and work in the field of science. Like *Moxi,* she doesn't know very well what she could do as an engineer. *Mohammed,* whose parents are both doctors, considered doing medicine, but preferred not to. For him, engineering education is *"a good start in life"* but it is not really his goal. He wants to create his own business, in the field of information technology, perhaps in Algeria where his parents come from. He really wants to do something useful and thought that a 5- year school would prepare him earlier for a profession than the *prepa* system.

(b) *Second type: the "dithering" students (nine students)*

The dithering students are undecided students whose main reason for being in an engineering *Grande Ecole* seems to be to delay decisions about their professional orientation. Although rather good at, or at least interested by, sciences, they are not particularly attracted by any engineering topics. Their presence in an engineering school is often the result of an absence of choice, of many decisions taken more or less consciously for them, rather than by them.

Mathilde's parents are both graduate engineers. They knew very well the educational system and encouraged their daughter, together with her teachers, to enter a very good *prépa*. She succeeded in entering the *Ecole Centrale of Lille,* a good engineering school, although not in the top ten, but she doesn't manifest any interest for engineering or technical matters. *Icham,* from Morocco, is the grandson of a graduate engineer from the prestigious mining school of Paris. He entered the mining school of Douai, although accepted in a very good second year class, because the school's rank in a magazine was good enough, and because he believed it was a generalist school. He discovered the schools' majors only when entering it. *Nicolas* failed to enter a *Grande Ecole* in political sciences and joined a scientific *prepa* to please his father, a high school teacher, who dislikes university and values the *prepa* system. He entered the school in Douai because his teachers told him he would not be able to get a better school the next year and he believes it is a "generalist" school. *Lucie* is in a 5 year curriculum at HEI. She is a rather good student brought up in an engineers' environment, but for her being an *"engineer is not a job, but a diploma that will allow you to do many jobs"*.

Amaury, at the *Ecole Centrale,* comes from an upper class Parisian family and was a low-average high school student in a top ranked institution. Before entering *prépa*, he believed that an engineer was a kind of industrial worker and the word "engineer" didn't appeal much to him. His parents, who are both very successful business people, considered that engineering was the good type of education for him. He wanted to study biology but followed their advice. *Celeste* was a low-average student in a very selective school. Coming also from an upper class family, her career will depend more on her parents' overdeveloped business networks than on her own determination to do something with her life. She was discouraged by her counsellor to go to a Business *Grande Ecole* and says *"engineering doesn't mean much to me (…) Once graduate, in general, no one ends up working in an engineering field"*. *Thomas* is the son of a very successful self-taught business manager. A low-average student at high school, he failed twice on the second year entrance exam but identified a major in medical engineering at HEI. His goal is *"not to become an engineer"* and will pursue an MBA. *Jérémy*, a low-average student was very interested in environmental issues and was pushed by his father, a medical doctor, to enter an engineer school because it is better than university; ISA was the only engineering school in the field of Life Science to admit him.

Damien's case is very different. Neither a son of an engineer or a teacher, nor coming for an upper class family, his parents are both self-educated and were not introduced at all in the higher education system. Being an excellent high school student, he was strongly pushed by his teachers to go to a preparatory class and ended up in the very best preparatory class of the country. There his goal became to be admitted in the best- ranked school in the country. He admitted during the interview that it was a strange way to choose for one's education and career. None of the students who entered the *Ecole Centrale of Lille* after completing prestigious *prepa* like Damien had decided to study in this particular school. When answering the very first question, "why are you here?" *Damien* answered quickly, "*because I didn't manage to enter the Ecole Centrale of Paris*". Having failed to join the "top ten", they did not feel like trying their chance a second (and last) time, mostly as the result of a profound boredom with the preparatory class. *Aurélie*, the "outsider" who ended up at *Centrale* after an unusual track, comments about her classmates: "*there are two main groups of students: those who are disappointed because they got "only" Centrale Lille, and those, like me, who had never dreamt it would be possible."*

19.5 Conclusion

The analysis of the interviews allowed us to highlight two main dimensions worth taking into account when trying to understand the engineering students' choice. The first relates to temporality, because choosing engineering is perceived by some students as a means to delay their professional choice, or even not to decide. A second dimension relates to their level of interest for engineering topics. The analysis also showed how much what should be a personal decision for one's future is shaped by more or less subtle scholar and family pressure, as well as a series of myths. Finally it showed how the choice to enter a scientific preparatory class is not conceived as a means to become an engineer in many people's minds other than the students', although the preparatory classes prepare only for the competitive exam to enter engineering schools. So why did they choose engineering education?

(a) *Because Grandes Ecoles' degrees are better than Universities'*

The choice of those students often appears as a negative choice: they (or their families, their teachers) discard the possibility of studying at University. One of the reasons is that French society is still very hierarchical, even in the companies, where strong importance is given to diplomas, hindering the recognition of experience and non-formal training. Within this strong weight given to the diplomas, there exists a subtle but rigid ranking between the diplomas. Since there is no selection process in order to be accepted into University, the University degrees are believed to be of poor quality.

Conversely, a "*Grande Ecole*" will be considered as awarding a diploma of high quality. Moreover, in upper class families, studying in a small "*Grande Ecole*" will quite often be considered a wiser choice that studying in an excellent University; the curriculum in the former will be (really) much easier, while the corresponding diploma is believed to be much better socially recognized.

(b) *Because it opens doors and enable to decide later on*

Another strong and widely held social belief in France is that engineering education is a "generalist" education, giving the possibility to do anything once acquiring the Engineer's diploma. This undiscussed belief is relayed by high school teachers and/or parents: "if you are good at sciences, you should go to engineering … you will be able to do whatever you want afterwards!" In fact, even the engineering schools themselves engage this kind of rhetoric; even the most specialized ones tend to present themselves as "generalist schools", because a diploma from a top ten school does in fact lead to a great variety of jobs, sometimes far from typical engineering jobs, and the students religiously recite it. Actually, for those who go through the *prepa* system, the 2 years of delay before the real choice does not help; the students are just intensively prepared to a competition based on very scholarly individual capacities. They neither learn to know themselves better, nor do they learn the various activities one can practice upon graduation. Instead they learn to respect the very rigid and very French, hierarchical organisation of academic grades.

(c) *Because they did not know what to do in their life*

Many students said that they went to engineering because they did not know what to do. Actually, in an educational system where selection means "to keep the best and to reject the others", they have no need to ask themselves about what they could do in the future; this kind of question is only for the losers. But this kind of secondary education encourages self-formatting and "fitting into the mold". It develops an early learning of social and scholarly segregation, but totally fails in terms of decision-making pedagogy. A more situational factor that also contributes to this would be the current environment of economic downturn and chronic unemployment. In such a context, to question oneself on one's vocation or the social usefulness of a profession may appear to be an unaffordable luxury when the main issue is how to survive in a jungle? The students' social background, often privileged, paradoxically does not help because the social pressure is no less in this social environment than in less comfortable backgrounds. Privileged environments will pressure their daughters and sons to reproduce the social model, to have a good standard of living and to reach the highest possible position.

What is the point of such a sterilizing system for the students as individuals, but also for the society as a whole, which is more and more in need of engineers? Obviously some questions need to be asked of secondary education, but also to the lower secondary and to elementary education, since the selective pyramidal model described above, starts at the youngest age. Questions may also be asked of the French system of preparatory class, which does not at all prepare the students to become engineers. One must conclude that this highly selective system ultimately works on erroneous criteria, that is if one intends to assess it in terms of the students' professional commitment, as well as in terms of ethical concerns about technologies and environment. Finally, questions should be asked of the engineering schools themselves, who cultivate ambiguity, and, as they begin to lack recruitment, try to mimic Business Schools, which tend to become the last trendy curriculum for a successful professional life. In the meantime, engineers are so much needed not only to contribute to the nation's economic growth, but also to take up the great challenges of development and sustainable development (UNESCO 2010).

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Chapter 20
Chinese Student Perceptions of Engineering Ethics

Heinz C. LUEGENBIEHL

Abstract The recent influx of Asian students into both graduate and undergraduate programs in the United States, primarily in the sciences and engineering, has raised concerns about the degree to which they share the same ethical background as domestic students. While a significant amount of research has been done on this issue in other disciplines, especially in business education, there has been relatively little study of engineering students, except in relation to general cultural differences and cross-cultural adjustment. Reporting the results of a survey of Chinese students' understanding of engineering ethics, this article represents a small step toward looking specifically at the acquaintance of a subset of Asian students with the topics commonly focused on in American engineering ethics teaching.

20.1 Introduction

Since the 1990s, colleges and universities in the United States have witnessed increasing enrollments of Asian students into both graduate and undergraduate programs, especially in science and engineering. This has raised some concerns about the extent to which that such students, despite their superior capabilities in mathematics and science, might not always share the same ethical assumptions as domestic students (Newberry et al. 2011). While some research exists on related issues in other disciplines, especially in business education (see numerous examples in the *Journal of Business Ethics*), there has been little attention to the situation in technical fields. In an effort to begin to address this lacuna, the following reports and analyzes the results of a survey given to Chinese students about their understandings of engineering ethics.

The survey was administered to two classes of seniors from two different graduating classes (2012 and 2013), with the results combined in this paper. A total of 157 students took the survey, of which 135 were males. Of the respondents, 110 were electrical engineering majors, with the remainder studying mechanical engineering.

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All surveyed students were enrolled in Shanghai at the University of Michigan (UM)- Shanghai Jiao Tong University (SJTU) Joint Institute (JI). The Institute was founded in 2006 and currently enrolls about 1100 students. Each year about 100 students transfer to the UM at the end of the sophomore year and are granted degrees from both universities at the completion of their studies. To give an indication of the quality of the JI students, they achieve a GPA of approximately 3.9 in their UM studies. The surveyed students completed all of their coursework at the Joint Institute. About 85% of JI graduate students immediately go on to earn graduate degrees in the U.S., mostly in the top ten engineering programs. All of the instruction at the JI is in English, with the exception of a few required humanities and social science courses, which are taught at SJTU. The engineering programs are closely modeled on the equivalent Accreditation Board for Engineering and Technology (ABET) accredited UM programs. The faculty stems from a variety of countries, but the majority consists of returned Chinese who received a Ph.D. in the U.S.

Besides background information questions, the survey consisted of 18 questions, of which nine were multiple choice and the remainder required a written answer. The complete list of questions, along with the responses to the multiple choice questions and a representative sample of written answers, can be found in the appendix to this paper. The questions were administered in a required two-hour course, “Professional Ethics,” prior to any instruction. One advantage of the present survey is that it could be administered in English, thus avoiding some of the typical problems of translation, which are often encountered in surveys of students in non-English speaking countries. A corresponding disadvantage is that the survey results are likely not representative of all Chinese engineering students, although they are more typical of the subset likely to study at the graduate level in the U.S. In formulating the survey questions, the author was particularly interested in the degree that their ABET style education in the Chinese context had influenced the students’ perception and knowledge of ethics; given that their professors had typically only received their graduate degrees in the U.S., the faculty on the whole at the JI skews toward a younger generation and the recent emphasis on ethics in graduate engineering education in the U.S. is likely to have an influence.

20.2 Data Presentation

On the whole, the responses to the multiple choice questions were not surprising. More revealing were their free form answers. Based on the multiple choice answers, the great majority considered themselves to be ethical persons (most of the time = 123; all of the time = 28). Parents (80) and teachers (66) were seen as the main sources of ethical beliefs, with friends (17) and religion (11) trailing. A large majority felt their JI education had helped prepare them to be an ethical engineer and deal with ethical issues, that discussion of engineering ethics in their technical class was important, and that the behaviors and attitudes of their instructors was important for demonstrating the importance of ethics for engineers. Conversely, only ten students reported having read a code of engineering ethics and 35 stated that they did not know what such a document was. Most surprising among the multiple choice answers was the result for the question, “How important is technical expertise as opposed to ethical concerns?” The responses were: Only the technical matters, 0; the technical matters more, 16; they matter the same, 95; ethics is more important, 45. (As in this question, not all question responses add up to 157, as a very few students left some answers blank.)

In the free form answers, the majority of students demonstrated some understanding of the nature of engineering ethics, although a significant minority had no exposure to the subject of ethics in any of their technical courses. In reply to the questions, “What is your definition of engineering ethics?” prevention of harm to society was the main subject mentioned, with students also emphasizing a sense of responsibility and the quality of honesty. However, when asked specifically about ethics topics discussed in their technical classes, a majority cited the JI honor code, which is focused on cheating and plagiarism, with fewer mentioning engineering responsibilities in particular. Most respondents who mentioned a specific course cited the freshman “Introduction to Engineering” course. The theme of the honor code and cheating was emphasized in students’ answers throughout the survey. Also common were peripheral issues such as class attendance and tardiness. A substantial minority indicated that ethics had not been discussed, with some indicating that they could not remember whether ethics had been discussed or not.

For characteristics of professionals, the answers relatively evenly divided between technical concerns such as knowledge and creativity, communication with colleagues, superiors, and the public, and ethical concerns such as honesty and adherence to rules. The theme of honesty in general was recurred throughout the survey answers. Dominant in the answers to issues students will have to deal with in their careers were potential conflicts between business concerns and engineering ones. In this section students also emphasized themes of conflict, such as loyalty and their own private financial interests being in potential divergence from the public good.

While the issue of public safety was mentioned explicitly by only a few students, many expressed a concern with the welfare of the public. The respondents felt that a sense of responsibility for the lives of others was crucial to being an engineer. They also expressed that a central role of an engineer is to improve the lives of people. A good majority believed that their education had prepared them to be an ethical engineer.

However, they also generally believed that their education had not given them enough preparation for dealing with professional ethical issues. Of course, the required course in which the survey was administered is expected to fulfill some of that function. When asked about specific ethical issues they might face in their careers, the answers were divided between ethical concerns such as honesty, bribery, and quality, and issues they had been exposed to in their education, such as plagiarism and teamwork. In light of the students’ previous answers, the responses to the final survey question, “How important do you think being an ethical engineer is?” were significant. As reflected in the multiple choice answers, the great majority indicated that being ethical is a central characteristic of being an engineer. Some went so far as to write that ethics is “very, very important.” The answers emphasized that in the absence of ethics, members of the public could get hurt or killed, reflecting the initial definitions given by the students.

The students' approach to engineering ethics appears to be mainly derived from their technical professors. Since the majority of students go on to study in the U.S., the Joint Institute has chosen to emphasize the issues of plagiarism and cheating throughout the curriculum. Students' understanding of ethics is also influenced by the fact that the JI, somewhat uniquely among Chinese universities, has an honor code and an honor council. This appears to greatly influence student perception of the nature of ethical issues. Yet underlying these specific concerns is an awareness that engineers have broader responsibilities to the public, although they are uncertain how these are to be exercised.

20.3 Analysis

The judgments in this section, while primarily based on the survey data, are also in part based on the author's 2 plus years of teaching in China (including in Taiwan), 3 years of teaching in Japan, and 30 years of teaching engineering ethics in the U.S.

The author's hypothesis that the survey would reveal a lack of acquaintance with the central concerns of engineering ethics as taught in the West was largely undercut by the survey results. As well, an assumption that loyalty to the group as opposed to the public that is evident in the study of Japanese engineers (Luegenbiehl 2004) did not hold for the surveyed group. Popular writing in China during the last several years has emphasized that Chinese young people are currently only concerned with materialistic gain and have lost all sense of morality. According to these perhaps hyperbolic essays found repeatedly in the *Shanghai Daily*, China is headed for a state of crisis. The results counter this contention for the group of engineering students in the survey.

The subjects exhibited a strong awareness of their engineering ethical responsibilities—this despite the fact that these do not appear to have been emphasized in their education, where more explicit attention was given to academic issues such as plagiarism and cheating. Since the most often cited source was the freshman introductory course, this either indicates the strong influence of this course, or the relative lack of emphasis on ethics in other courses. The freshman course has a strong design element where students work in small teams and thus, is unlike their other technical courses, which are all large lecture courses. Several students also mentioned their senior design course as a source of ethical discussion. However, many of the students had not yet taken this course at the time they took the survey.

The topics most often mentioned specifically correspond closely to those highlighted in Western codes of engineering ethics, although few students reported having read a code of ethics. These include responsibility for the public welfare, honesty, confidentiality, responsibility for one's actions, and loyalty, as well as giving credit for work done by others. Only a couple of very general, rather obscure codes for engineers currently exist in China. The author can only hypothesize that these issues are mentioned by their instructors, although perhaps not in such a way that they embed themselves as a remarkable feature of instruction. In the students' answers, the association of these topics with specific engineering contexts is too frequent and too consistent to be accidental or to arise out of the non-engineering phases of their prior education. Thus, there seems to be no great distinction from the types of responses that would be given by U.S. engineering students. Based on the author's own experience, from the point of view of an ethics instructor, there is perhaps an even greater awareness of ethical responsibilities among the sampled group than would be among a similar group of American students.

Based on the author's teaching experience in China and Japan, one of the surprising discoveries was that the respondents focused to a large extent on their individual responsibilities rather than on those of the group. In China, students are hesitant to speak up in class unless they believe there is consensus on an issue; Japanese students value loyalty to the employer above all else, even responsibilities to the public (Luegenbiehl 2004). This led to the conclusion that the responses of the Chinese students would be similar to those of Japanese students, since both have a historical foundation in Confucianism. However, it is well known that during the Maoist era Confucianism was discouraged in China and has only recently begun a resurgence with an emphasis on traditional values. Overemphasis on the alignment of different Asian nations in terms of values may therefore be a mistake.

Based on the written responses it seems clear that the emphasis on an honor code and its enforcement, as well as the behavior of technical instructors, has a great deal of influence on the thinking of the students. One of the complaints that is sometimes heard from the students themselves is that in their pre-college education, what would be considered plagiarism or dishonesty in the West would be ignored or even encouraged. This is related to the general college entrance examination that students need to take, which relies heavily on memorization and repetition. As indicated previously, the surveyed students are perhaps not typical of Chinese students since their college years emphasize a different methodology, perhaps another reason why the introduction to engineering course has a profound impact on their academic careers.

One caveat to the analysis that must be mentioned is that the survey was given as part of the required professional ethics course, even though it was administered at the beginning of the first day of class. It is therefore possible that some of the answers were tailored to provide the information that the students believed the instructor would want to hear. However, this does not obviate the fact that students did demonstrate acquaintance with the topics commonly raised in engineering ethics courses in the West. Only a very few students wrote, as did one student, in reply to the question, "What is engineering ethics?": "I have no idea. I think I will know it after learning this class."

20.4 Recommendations and Conclusions

First, unlike for the previous generation, there is currently a movement for Chinese academics to return to China rather than remaining abroad. As more of them become integrated into the Chinese academic system, it can be expected that they will begin to integrate an ABET style approach into Chinese engineering education. This will be coordinated with the Chinese government's call for increased emphasis on creativity in technical education as a goal for furthering national advancement. These two forces make it increasingly likely that graduate students will have less difficulty adjusting to Western ethical standards in the future. There should also be an effort made to have a pre-college design course made available as an option for students in China who plan to study engineering, on the model of similar pre-college summer programs available to high school students in the U.S. Alternatively, in admitting technical students as freshmen in the U.S., colleges could offer a summer design experience where designs are constructed in a broader societal context.

Second, the survey makes clear that the existence of an honor code that is emphasized throughout the curriculum has the potential to greatly influence student thinking about ethics, even if it is not focused on engineering ethics specifically. At the JI, for example, the honor code is read at the beginning of every semester in every course and students are well aware that violation of the code has serious effects on their academic careers. It should also be mentioned that what is understood by plagiarism and cheating does not always correspond between China and the West, and this should be emphasized to students soon after their arrival in the U.S.

The most important outcome of the survey is to demonstrate the influence of instructors on the beliefs of Chinese students. This is not a novel finding, but it does point to opportunities for the way in which the concern about ethics can be integrated into Chinese engineering education. It seems likely to the author that the potential for such influence is greater among Chinese students than Western ones, because instructors are still held in very high esteem in the Chinese educational system. In a broader picture, the survey points to how current concerns regarding plagiarism and "cheating" by foreign students in the U.S. could be alleviated, namely by giving greater emphasis to these issue in their home countries.

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Appendix

For this report, the order of questions has been rearranged. Free responses and multiple choice questions were intermixed in the survey instrument.

Multiple Choice questions (N = 157). The answers provided do not always add up to the total survey group as a few students omitted answering one or more of the questions. Several of the multiple choice questions are modeled on those in the Robert McGinn (2006) survey included in the references.

1. Do you consider yourself to be an ethical (a moral) person?

Never: 0 Some: 23 A good amount: 59 A lot: 70 No opinion: 4

2. What is the main source of your ethical beliefs?

Parents: 80 Teachers: 66 Friends: 17 Religion: 11 Other: 5 (Internet = 2)

3. Has your JI education helped prepare you for being an ethical engineer?

Not at all: 1 Some: 49 A good amount: 55 A lot: 55 No opinion: 3

4. Has your JI education shown you how to deal with engineering ethical issues?

Not at all: 5 Some: 64 A good amount: 55 A lot: 30 No opinion: 3

5. How important do you think discussion of engineering ethics in your technical classes is?

Not at all: 1 Some: 23 A good amount: 59 A lot: 70 No opinion: 4

6. Does the behavior and attitudes of your JI teachers show that ethical behavior is important for engineers?

Not at all: 0 Some: 39 A good amount: 54 A lot: 54

7. How important do you think taking a course on professional ethics is?

Not at all: 0 Some: 12 A good amount: 61 A lot: 77 No opinion: 5

8. Have you ever read a "Code of Engineering Ethics?"

Yes: 10 No: 112 I don't know what it is: 35

9. How important is technical expertise as opposed to ethical concerns?

Only the technical matters: 0 The technical matters more: 16 They matter the same: 95 Ethics is more important: 45

Free Answer Questions. Several representative answers are included for each question. Spelling and grammar are preserved from the originals. Although only a few samples are included, all of the survey respondents answered the free answer questions.

1. What is your definition of engineering ethics?
    - "Engineer's common belief to limit the behavior of engineers and prevent them from doing harm to other people's lives, prospects and common value of society."
    - "The rules and disciplines an engineer has to obey in his/her career."
    - "As an engineer what should I do and what I cannot do."
2. What do you think the most important issue in engineering ethics is?
    - "To be honest to everyone."
    - "Be responsible to what you/your team have done."
    - "Knowing what is forbidden like so some harmful research or betray your teammates."
3. Have any engineering ethics issues been discussed in your technical classes at JI? If so, what?
    - "Yes, in VG100 [Introduction to Engineering] Professor "X" talked about the concerns of an engineer should be what the people need and something making the world better."
    - "In VG100, I had some discussion in the moral problems of engineering setting; engineers are challenged when they are pressed for efficiency and safety is overlooked and when they discover dishonesty of their partners and managers."
    - "Yes, no cheating or communication during the exams and no copying other's work in the project section or homework section."
4. Give one example of how your JI teachers show that ethical behavior is important for engineers.
    - "Take serious attitude to every thing what they do and be honest."
    - "When doing some experiments, the safety rules are set very carefully, so that nobody will hurt."
    - "Some professors would check if some students copy others' work and against the honor code."
    - "One gave examples of engineering products that harm the society."
    - "Instructors always cites the source of the materials they find in other technical papers."
5. List the top three subjects that a set of rules for engineering ethics should discuss.
    - "Whether it benefits the human; honest or not; useful or not."
    - "Honesty; justice; objective."
    - "Safety, environmental friendly, cheating problems."
    - "Responsibility; attitude towards work; honesty."
    - "Social responsibility; copyright; honesty."

6. How would you decide that something is an ethical issue?
    - “By seeing whether it is good for the public.”
    - “Something will affect others is an ethical issue.”
    - “Refer to the law and culture.”
    - “According to the code of engineering ethics.”
    - “Something that is about moral standards but has nothing to do with laws.”
7. List the three major characteristics of being a professional.
    - “Technical expertise; morality; creativity.”
    - “Knowledgeable; creative; responsible.”
    - “Honesty; loyalty; stick to one’s own opinion.”
    - “Good in technical matters, good teamwork ability, ethical perfection.”
8. What kind of ethical issues do you expect to face in your career? List three examples.
    - “Keep the secrets of company.”
    - “The conflict of the interest of the public and the company.”
    - “Being honest to the public about the disadvantage of your product.”
    - “Copyright; use something that is already created by someone else.”
    - “Making a decision between money and safety.”
    - “A conflict between my own benefit and ethics.”
9. How important do you think being an ethical engineer is?
    - “Very important, because a engineer without ethical beliefs can do much harm to the society.”
    - “Very important, if not, the career may be ruined.”
    - “It is very important to be a great engineer, but it will may be useless if you just want to be an engineer.”
    - “In my opinion only the ethical engineer can be seen as engineer.”
    - “An ethic engineer can make people’s life better while a non-ethic one may bring the life into disaster.”
    - “An engineer without ethics is like a person without soul.”

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Chapter 21
Engineering Policy: Exploratory Reflections

Carl MITCHAM (with ZHANG Kang 张亢)

Abstract In the extensive literature on science policy, there is little discussion of engineering policy. Yet in many instances the science in science policy discourse is really engineering, and engineering is often as important for public policy formation and implementation as science. Science policy discourse commonly distinguishes between "science for policy" and "policy for science," a distinction that can also be used to examine engineering policy. Engineering for policy includes both engineering advice to policy makers, such as where to construct a dam or what standards should be established to achieve a certain level of safety, and actual engineering to achieve policy goals, such as designing, constructing, and operating an electric power grid or public transport system. Policy for engineering focuses on such questions as how much to fund engineering education or to promote ethics in engineering. Reflection is extended by considering engineering policy related ideas in the work of engineer Henry Petroski and policy scholar Roger Pielke Jr., both of whom address issues in the American context. An appendix makes brief reference to engineering policy in the Chinese context.

21.1 Introduction

Although it is common to talk about science policy, the term "engineering policy" is something of an anomaly. *Wikipedia* has a substantial article on science policy but none on engineering policy. A Google search on the term "science policy" (March 2017) turned up 2.8 million hits, whereas "engineering policy" yielded only 140,000 (5% as many). The related terms of "industrial policy," "technology policy," and "innovation policy" came in respectively at 2.4 million, 2.2 million, and 600,000 hits, making "engineering policy" something of a step-child in the technical policy

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arena. Although engineering associations, such as the Royal Academy of Engineering in London and the National Academy of Engineering in Washington, DC, have web pages devoted to engineering policy, they provide little in the way of general analysis of the topic. They nevertheless suggest that the engagements between science and public affairs to which science policy refers involve engineering as well, often even more than science. Indeed, the thesis here is that in many instances the science in science policy discourse is really engineering, and engineering is as important for public policy formation and implementation as science. A preliminary effort to substantiate this thesis will proceed by way of conceptual and historico-philosophical background, followed by consideration of two normative arguments, one from an engineer, the other from a science policy scholar.

21.2 Conceptual Issue: What Is Policy?

"Policy" is a term with relatively recent, primarily English language origins. It is closely related to but not the same as politics. So close is the relationship that in French, the English "politics" and "policy" are equally translated as *politique*. In Spanish, "policy" is translated, depending on context, as *política*, *norma* (rule), and *póliza* (as *póliza de seguros* or "insurance policy"). Note also how vocalizations of the French and Spanish words for "police"—*police* and *policía*—sound like the English "policy," which does in fact connote policing or making sure things are done in accord with certain rules. In German, "policy" is translated with even more differentiation: e.g., as *Politik, Police, Regel, Taktik*. Similar situations occur in many other languages.

According to the *Oxford English Dictionary*, "policy" first occurred in the 1400s; although closely associated with politics, it seldom (if ever) appears in English translations of classic texts such as Plato's *Republic* or Aristotle's *Politics*. Its linguistic presence has nevertheless steadily climbed from 1800 (with a Google n-gram of 0.0060%) to 1980 (when its n-gram was 0.0220%—roughly a fourfold increase). (The google n-gram is a statistical measure of the frequency of terms in printed texts between 1500 and 2008 collected in the Google corpora.)

Simplifying for present purposes, politics concerns power, whereas policy concerns reason. (Google n-grams again provide modest empirical support for this analytic distinction: "power politics" is three times more likely than "power policy"; "rational policy" is five times more likely than "rational politics.") Political actions are characteristic of the state, and the state, according to Max Weber's analysis, is defined not by any distinctive ends, but by its distinctive means: physical force. "In the past, the most varied institutions … have known the use of physical force as quite normal." Violence was an accepted part of family life and in religious institutions. "Today, however, [the] state is a human community that (successfully) claims the *monopoly of the legitimate use of physical force* within a given territory" (Weber 1946, p. 78). The successful monopolization of force can be justified on the basis of tradition and/or raw violence or the threat of its use. In all cases, however, political decisions are ultimately based on force: either by some group that has a monopoly on weapons and is thus able to dominate or by a democratic majority being accepted as more powerful than any minority. In politics, reason remains in the background.

In policy, however, reason comes to the fore: there is an effort to replace violence with reason. Policy decisions claim to be rational decisions determined by more than simple power. They can result in the use of force, but are not made on the basis of force, except the non-physical force of reason. Insurance companies write their policies on the basis of statistical information about the likelihood of certain events. Democratic legislatures make laws, primarily on the basis of interest group pressures. In these laws (which are, of course, sometimes called policies), power is often delegated to some set of experts to determine the precise policies that need to follow. A law may be passed to make transport safer or protect the environment, but the formulation of policies for transport regulation or environmental protection are delegated to government agencies with specialized knowledge and expertise.

The European Enlightenment witnessed a historic effort to replace politics with policy—that is, to replace tradition (especially religious tradition) and physical violence with reason, especially the reason of science, as a key determinate of governmental decision making and action. To this end, the state itself established agencies to provide it with scientific information about such things as the size of the population, economic activity, health, and more. As has been argued in detail by Yaron Ezrahi (1990), the state support of religion was exchanged for state support of science, a move exemplified especially in the American and French republics. One argument for this replacement was simply effectiveness. Science provides the kind of knowledge that can make political decisions more effective. Political decisions made by people simply because they have power (or the will to power) often fail in the pursuit of their goals, as in the failures of the Crusades, the Spanish Armada, and Napoleon's invasion of Russia. A strong will is not enough to guarantee success, even when the strength of will is based in democratic agreement and determination.

The policy promise can take three overlapping forms. First, scientific research should provide information for how politically determined goals might be operationalized. Second, a scientific assessment of political (that is, non-scientifically determined) goals should be able to veto or modify any attempt to pursue goals that are not feasible. More positively, science can provide background knowledge for the political formulation of goals that are feasible. An example of the first type might be a political decision to provide safe drinking water to a city. Politicians must rely on scientists to implement or operationalize such a decision, since politicians as politicians do not have the knowledge necessary to decide what constitutes safe drinking water (e.g., what levels of various microorganisms and chemicals should be allowed in the water system). An example of the second type might involve scientific criticism of a political decision to send humans to Mars. Given the technical means available at present and what we know about human physiology, a human mission to Mars would not work; the astronauts would die.

In definitional terms, laws are rules created by the state to regulate its members and are enforced by governmental power. But since laws that are created by power are not necessarily rational, they are often ineffective. In contrast, policies can be defined as science-based guidelines for behavior for the effective realization of well-chosen goals and clearly designated outcomes. Insofar as science makes the dominant claim to reason in the modern period, so that all policies are based in science, "science (or scientific) policy" might well be described as a pleonasm.

In both of these two promises, science remains ultimately subservient to politics. Science concerns only means, not ends. Politics or power decides what goals to try to pursue, then science determines whether, to what extent, or how such goals are able to be pursued effectively. Science only disposes; it does not itself propose goals.

However, beyond these two standard promises about the proper role of science in public affairs—that is, to operationalize and to veto (or modify) political decisions—some have made a more expansive claim. For many scientists, the scientific way of life is a good that they propose as a goal deserving of governmental support. John Dewey (1927) and Michael Polanyi (1962), for instance, have argued that the methods of science should become the methods of politics. Additionally, some scientists argue that the scientific study of human beings or human evolution provides insight about the true goals of human behavior. However, in political regimes where many citizens question the influence of science, this third promise is extremely contentious. Science, technology, and society (STS) studies would further question the idea of a science distinct from society that could become its model.

21.3 Background: Classics in Science Policy

Although the movement from politics to policy has its roots in Enlightenment political theory, the actual development of policy theory did not take place until the twentieth century. In this regard, it is possible to reference three classic contributors to science policy theory formation: the Americans Harold Lasswell (1902–1978) and Harvey Brooks (1915–2004), and the Frenchman Jean-Jacques Salomon (1929–2008).

Political scientist Harold Lasswell coined the term "policy sciences" to refer to all sciences insofar as they can be made relevant to public policy formulation. The concept grew out of his positivist view of political science as the study of power dynamics in society. Lasswell's *Politics: Who Gets What, When, How* (1936), which contributed to the behavioral research program in political science, saw elites as the primary power holders. In numerous other works, such as *Propaganda Technique in the World War* (1927), *Psychopathology and Politics* (1930), *Power and Personality* (1948), and *Political Communication: Public Language of Political Elites in India and the United States* (1969), he examined how elites could beneficially influence publics, and argued especially for the social sciences to apply themselves to serving a democratic commitment to social justice.

Most important in the present context, however, is Lassell's 1951 article on "The Policy Orientation." There he contrasted policy and politics by describing "'policy' [as] free of many of the undesirable connotations clustered around the word political, which is often believed to imply 'partisanship' or 'corruption'" (Lasswell 1951, p. 5). The policy sciences are further described as the content of all sciences marshaled for increasing the intelligence of decision making, along with the scientific study of the decision- making processes themselves. The need for both arose from the increasing complexities of contemporary democratic life under Cold War tensions and the technological advances in global communications and increased global interactions.

Lasswell names multiple social science disciplines—economics, psychology, sociology, anthropology, social work, social geography, history—as contributors to the development of the policy sciences. Relevant as well is "the knowledge of atomic and other forms of energy which is in the possession of the physicists and other natural scientists" (Lasswell 1951, p. 14). He further describes "the problem attitude"—that is, a focus on solving problems—as central to the policy orientation. Despite the fact that nuclear engineers know more about atomic energy than physicists, and that engineers self-describe their profession as dedicated to problem solving, engineering is conspicuous by its absence in the Lasswellian constellation of the policy sciences. (This is also largely true in the broader field of policy studies.)

Harvey Brooks—physicist, Dean of Engineering and Applied Sciences at Harvard, and science policy adviser in the administrations of Presidents Eisenhower, Kennedy, and Johnson—introduced a variation of Lasswell's distinction between content and method as one between "science in policy" and "policy for science." Science for policy is concerned with bringing science to bear in public policy decision making, whereas policy for science deals with examining and optimizing "the mechanisms, institutions, and operating principles through which federal resources are channeled into scientific and technological activities" (Brooks 1968, p. 254). In contrast to Lasswell, Brooks is more concerned with the latter than the former. From this perspective he considers, for instance, the strengths and weaknesses of the decentralization of governmental science funding versus the establishment of a federal ministry of science, or the funding of basic versus applied research.

Criticizing the positive views of science for policy (as in Lasswell) and policy for science (as in Brooks), the French philosopher and OECD administrator Jean-Jacques Salomon articulated the first extended criticism of the notion. In *Science and Politics* (1973), Salomon sought "to denounce [the] misuse of science and technology [and] the complicity of most scientists [in politics]" (p. 255). This denunciation proceeded through a broad brush history of relationships between modern science and society to a critical examination of "politics in science" and "science in politics." The latter involves scientists attempting to exercise political power and naively failing to appreciate their incumbent responsibilities at both national and international levels. For Salomon, it is an illusion that scientific policy can ever replace politics, because science itself is infused with politics.

21.4 Science, Technology, and Engineering

In their positive stances, neither Lasswell nor Brooks make strong distinctions between science, technology, and engineering; instead they tend to subsume technology and engineering within science. Folk philosophy distinctions, though contested, can nevertheless be useful here: science produces knowledge, engineering produces technologies, that is, physical artifacts (from large-scale structures and infrastructures to consumer goods). Communities of scientists and engineers clearly differ, and technologists seem always to be ranked a little lower in the society in which everyone nevertheless desires technologies. The n-grams for these three terms reveal a relatively steady English linguistic presence of "science" from 1800 to the present, a meteoric rise in "technology" from the 1940s (from 0% to the point where it is on par with "science"), and a slow rise of "engineering" (from very low in the mid-1800s to about one third as prominent as "science"). Insofar as "technology" refers more to artifacts than to knowledge, as our lifeworld is transformed into a techno-lifeworld suffused with technological objects, "technology" just naturally increases in usage.

These distinctions are mirrored in common policy parlance. Using *Wikipedia* again (accessed March 2017, as a source that reflects common intellectual beliefs), science policy is defined as concerned with "understanding the processes and organizational context of generating novel and innovative science and engineering ideas"; technology policy as the "public means for nurturing [technology or the "capabilities, facilities, skills, knowledge, and organization required to successfully create a useful service or product"] in the service of national goals and the public interest" (quoted from American science policy advisor Lewis Branscomb 1995, p. 186); and industrial policy (a term whose n-gram numbers eclipse both "technology policy" and "science policy") an "official strategic effort to encourage the development and growth of part or all of the manufacturing sector." As already mentioned, there is no article on, and hence no *Wikipedia* definition for, engineering policy. But insofar as all these common beliefs focus on some form of policy for promoting science, technology, and industrial development they implicitly include engineering, classically defined as "the art of directing the great Sources of Power in Nature for the use and convenience of man" (royal charter of the Institution of Civil Engineering, 1828). Engineering policy would then be constituted by efforts to promote engineering education, research, development, and construction for the "use and convenience" of national goals and national commercial enterprises.

The extent to which science policy discourse has become focused on policy for science, engineering, and technology at the expense of science for policy reflects the degree to which science, engineering, and technology have become integral to the techno-lifeworld in which we now live. Indeed, in the science for policy area, even when unthematized as such, engineering for policy is pervasive. Engineering for policy includes both engineering advice to policy makers (where to construct a dam or what standards should be created to achieve a certain level of safety in a project) and the use of actual engineering to achieve policy goals (designing, constructing, and operating an electric grid, water system, or public transport infrastructure). Despite their differences, the common marginalizing of "engineering" in Lasswell, Brooks, and Salomon all contribute to an on-going failure to appreciate the importance of engineering. As one recent example, take the handbook on *Science of Science Policy* (Fealing et al. 2011), which aims to examine how science policy really works. Throughout chapters on theory, empirical research, and practice—

with repeated references to the need to promote innovation and solve problems—engineering remains a step child; the term "engineering" does not even occur in the index. The only chapter that begins to acknowledge the central role of engineering to enhancing public policy decision making is on "Technically Focused Policy Analysis" written by Granger Morgan, the director of an academic engineering and public policy program. It includes a short paragraph reference to "engineering analysis" and notes that "simple ignorance or misunderstanding of the natural world or of engineered systems will ... lead to silly and ultimately unrealistic policy outcomes" (Fealing et al. 2011, p. 127). One engineer who has given even more force to this argument, which is more normative than conceptual, is Henry Petroski.

21.5 Normative Arguments: Henry Petroski

In *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (2010), civil engineer Henry Petroski extended an argument threaded through more than 14 books published since 1985. His argument is that, although fraught with costs as well as benefits, engineering is a uniquely human activity with special abilities to redesign the world as a more humanly habitable place. In the present instance, the argument is deployed with special reference to policy questions involving climate change, energy, and related challenges. Petroski argues that the utility of engineering to policy requires an appreciation of its distinction from science and the range of engagements that engineering has with politics.

Petroski begins with a review of the ubiquity of risks in human affairs and maintains that risks are what science and engineering attempt to overcome. Using the risk of asteroid impacts as an example, he argues that, "scientists warn, engineers fix." Engineering is nevertheless more complex than it may initially appear. As much or possibly more than medicine, engineering deserves credit for two centuries of increases in human health. Although science can sometimes precede engineering, the opposite is also the case.

For example, scientists use engineering techniques when they construct hypotheses and the instruments for testing them. Additionally, even when engineering fixes, the fixes can have unintended consequences that need their own fixing. Petroski calls these "speed bumps," noting that speed bumps themselves illustrate the problem: while slowing traffic, they increase fuel consumption, pollution, and noise as cars slow and resume speed, and impede emergency vehicles. Good speed bump design requires systems engineering that, *plus respicere*, takes more into account than the simple bump itself (see Mitcham 1994).

Petroski then takes up specific public policy challenges and considers how science and engineering might address them. Leading off is a discussion about energy, with a broad overview focused on the public policy context in the United States over the past half century that has effected energy development related to nuclear, wind, solar, geothermal, batteries, oceans, pedestrian power, biofuels, conservation, fuel cells and hydrogen, and natural gas. In considering such a plethora of energies, Petroski reiterates his brief for a systems engineering approach by quoting “the legendary engineer-educator Hardy Cross” to the effect that engineering practice is involved with three trilogies: “The first is pure science, applied science, engineering; the second is economic theory, finance, and engineering; and the third is social relations, industrial relations, engineering” (Petroski 2010, p. 145). However, engineering is more related to social problems than to pure science, because “engineering is all about designing devices and systems that satisfy the constraints imposed by managers and regulators” (Petroski 2010, p. 155).

A further discussion of complex systems draws initially on the history of dam construction and its discontents to note how science-engineering-society relations are becoming increasingly complex: First science supports dams as sources of power, then it criticizes them as causes of environmental damage. The “windshield wiper” input from science is equally well illustrated by a back-and-forth movement in healthcare debates; one study points up the benefits of something that another study indicates is harmful. In truth, “the solution to problems involving complex systems can be expected to require the involvement of complex systems of people and approaches” (Petroski 2010, p. 172). Using the examples of earthquakes and hurricanes, Petroski distinguishes between uncertainty in science and engineering. “Generally speaking, the responsibility of the scientist qua scientist ends with the warning, which is where the responsibility of the engineer begins” (Petroski 2010, p. 185). Scientists can predict earthquakes and hurricanes with some level of probability, to which engineers can respond with designs utilizing safety factors, which are in effect efforts to mitigate uncertainties. But then policy makers must decide how to allocate resources among competing predictions, designs, and financial pressures.

Petroski concludes by reviewing engineering achievements of the twentieth century, challenges for the twenty-first century, and the newly emerging science and technology policy of seeking to meet challenges by offering large-scale prizes for doing so. The review of achievements, as catalogued by the U.S. National Academy of Engineering (NAE), highlights the extent to which electrification, the automobile, airplanes, and more all depend on interdisciplinarity, can never be perfect or finished, and do not come without costs. “These are important lessons to remember when engineers look to tackling and are looked to for tackling the global problems that threaten planet Earth” (Petroski 2010, p. 211) as itemized in another NAE list of 14 challenges judged essential to future human flourishing. However, “as much as the inadvertent harmful by-products of technological achievement might be blamed for everything from local smog to global warming, it is also solid engineering and enlightened public policy that will be necessary to reverse the negative effects and bring forth new achievements for a new time” (Petroski 2010, p. 212).

Enlightened public policy becomes such, in Petroski’s view, through acceptance of engineering policy advice. An example in regard to energy policy is the vision of a “2000-watt society” advanced by an engineering faculty at ETH Zurich. The aim is to reduce energy consumption to the world average of 2000 watts per person in Europe (where usage is 6000 watts per person) and the United States (a 12,000-watt society), while allowing countries such as China (a 1500-watt society), India (a 1000-watt society), and Bangladesh (a 300-watt society) to increase consumption.

No serious technological breakthroughs are needed to achieve the goal, since Switzerland actually had a 2000-watt society as recently as the 1960s. The only problem is the enlightened political will to make the vision a reality. But what evidence is there that such a political will exists or is likely to exist? While engineering is essential, even more so, Petroski suggests, is an enlightened public. Yet there is nothing in his argument that gives much reassurance that the many will become enlightened and either listen to the warnings of scientists or enact the designs of engineers.

21.6 Normative Arguments: Roger Pielke, Jr.

Further normative issues are raised by considering the work of policy analyst Roger Pielke, Jr. In *The Honest Broker: Making Sense of Science in Policy and Politics* (2007), Pielke argues for recognizing four different ideal type approaches to science for policy, that is, for scientists offering advice to politicians and policy makers: the pure knowledge exponent, the advocate, the arbiter, and the honest broker. To what extent does Pielke's analysis apply to engineers who might make design recommendations for addressing a public problem?

To illustrate his distinctions, Pielke imagines someone asking for help in finalizing dinner plans. The scientist who acts as a pure knowledge exponent responds like a detached bystander lost in his own world; he describes the physiology of digestion and chemistry of nutrition, which may be interesting, but is probably not immediately helpful. The issue advocate scientist, by contrast, acts like a salesperson and immediately argues for Joe's Steak House right down the street, but with a peculiarly scientific rhetoric that deploys information about the number of meters distant and the special nutritional qualities of bovine muscle tissue heated sufficiently to unwind the molecular protein bonds in a process known as denaturing. In another contrast, the arbiter scientist behaves more like a hotel concierge. She questions any inquirers about what they want from dinner: healthy nutrition, good economic value, quiet and safe ambience? Once informed that the primary concerns are affordability, quietness, and safety, she identifies the most acoustically well designed restaurants under good management in the neighborhood within a certain price range. The arbiter scientist engages with the public and communicates knowledge guided strongly by publicly expressed needs or interests. Finally, the honest broker scientist distances herself from the immediate needs or interests of any inquirer and, without asking for such contextual details, offers a matrix of information about restaurants in the area covering, for instance, nutritional value, price range, ambience, distance, and more. The effect will often be to stimulate re-thinking on the part of inquirers—perhaps a re-consideration of the needs or interests with which they may have been operating, even if they were not consciously aware of doing so.

In considering the strengths and weaknesses of each ideal role, Pielke defends the importance of the honest broker, and is especially critical of what he calls a "stealth advocate": that is, the policy adviser who claims to be an honest broker, but is really arguing for a particular action or set of actions. To what extent might Pielke's argument apply to engineers rather than scientists advising policy makers? To what extent might thinking about the applicability of his analysis to engineers even raise questions about Pielke's distinctions?

When applied to engineering, the honest broker role seems peculiarly inappropriate if not impossible. In the first place, it is not clear that Pielke's ideal is even possible.

Are there any scientists who are not influenced by their own values in the kinds of research they do and the conclusions they draw and/or think significant enough to communicate to others? An honest broker scientist may exercise some detachment from the immediate needs or interests of any particular inquirer, but will find it much more difficult to be detached from her own personal interests. A scientist is unlikely to be doing research on the physiology of nutrition without some personal interest, and certainly what to include in any informational matrix will reflect what she judges to be significant. For instance, even an honest broker will be unlikely to include the political or religious affiliation of restaurant owners, rejecting this information as scientifically irrelevant, even though there are certainly numerous Americans who would be quite interested in using such information to help inform their decision making.

Additionally, it is not clear that someone seeking advice from a scientist really wants an honest broker to just lay out a matrix of alternatives. As more than one policy scholar has noted, science can actually upset politicians and policy makers. President Harry Truman, for instance, is alleged to have objected to economic advisers who would say "on the one hand" and "on the other hand." Instead, Truman said what he really wanted was "a one-handed economist" (Haas 2005, p. 386). Politicians and policy makers would rather have adversarial advocates than honest brokers.

With regard to engineers, first, seldom will any engineer be tempted to act as a pure knowledge exponent. Indeed, this is probably a *reductio ad absurdum* option even among scientists. Engineering as a profession has built into it a rejection of knowledge for its own sake, always wanting to use whatever knowledge about the world will work to help solve a particular problem.

Second, insofar as engineers work in and for particular companies or institutions, they are unlikely to be able to function as issue advocates, except as issue advocates for the kinds of practical skills and expertise found in their companies. How could an aeronautical engineer working for Boeing Airplane Company, when giving policy advice on the construction of, say, a West Coast transport system, recommend anything other than an air-transport system? Aeronautical engineers would not know enough about either automobiles or trains to advocate for them—not to mention the fact that, were a Boeing engineer to venture such advocacy, it would likely be at the sacrifice of current employment.

Third, even more than scientists, it is hard to imagine engineers functioning as honest brokers. The job of engineers is to design particular, real-world solutions to problems that have been specified for them in advance. In the real world of decision making, two (or more) handed engineers are even less welcome than two handed economists.

Finally, the most likely model that engineers use to offer policy advice is as technical arbiters: providing a matrix of options for design and construction of projects, among which clients then decide. The arbiter engineer, by virtue of being a professional engineer, necessarily communicates with some public, whether inside the company or out. Engineers, qua engineers, are guided strongly by well-expressed needs or interests from their clients or the public.

21.7 Conclusion

The modest exploratory thesis here, developed from both conceptual and normative perspectives, has been that science policy is often really engineering policy. Conceptually, much alleged science policy is just as much or more, engineering policy. Normatively, engineering advice is crucial—often even more so than scientific advice—to public policy decision making. Just as with science, however, there are problems with the public acceptance of engineering advice, and only as technical arbiters are engineering advisers likely to function in anything approaching effective ways.

This argument nevertheless remains incomplete. Other questions that naturally occur include the following: What is the relationship between engineering policy arbiters and technocrats? Is engineering policy simply another term for technocracy? What is the relationship between engineering policy and democracy? Only by consciously recognizing the political and philosophical complexities of engineering advice can engineering itself began to become more beneficially integrated with politics and policy.

Acknowledgment The discussion here draws significantly on two previous publications: “Petroski’s Policy,” *Technology and Culture*, vol. 52, no. 2 (April 2011), pp. 380-384; and “Ethics and Policy,” in Ruth Chadwick, ed., *Encyclopedia of Applied Ethics*, 2nd ed. (San Diego: Academic Press, 2012), vol. 2, pp. 165–172 (co-authored with Erik Fisher).

Appendix

A Note on “Politics” and “Policy” in China (with ZHANG Kang 张亢)

This chapter distinguishes between politics and policy, using the English terms, arguing that politics refers more to the use of power and policy to the use of reason in the making of decisions, especially in public affairs. Given the effort of the book as a whole to bridge East and West, it seems appropriate to include a note on relationships between two related terms in Chinese.

In Chinese the term commonly translated as "politics" is 政治 (*zhengzhi*) and as "policy" is 政策 (*zhengce*). Both involve the character 政, which means related to national or public affairs. It can be found in many other combinations such as 政体 (*zhengti*, polity), 政府 (*zhengfu*, government), 政党 (*zhengdang*, political party), 政治学 (*zhengzhi xue*, political science), and 政治哲学 (*zhengzhi zhexue*, political philosophy). Thus 政 has the connotation of power or violence. So in Chinese both 政治 (politics) and 政策 (policy) implicate power. It is difficult to say that this is true more of the former than the latter.

At the same time, there are some similarities with English in the way the two terms are used in Chinese. The Chinese character 治 (*zhi*) means "manage" so that 政治 (*zhengzhi*, politics) can imply managing national or public affairs, which almost inevitably involves an ultimate recourse to power or violence. By contrast, the character 策 (*ce*) in its original meaning refers to (a) the bamboo whip for controlling a horse and (b) bamboo slips on which texts were once written. Usage (a) implies guidelines and rules; usage (b) implies recording or answering some political or economic questions in the ancient imperial exams (科举), thus naturally related to strategy or planning. In contrast with 政治(politics as an activity), 政策 (policy) suggests guidelines or rules and assignments to achieve political goals; it is more like some detailed measures and explicit rules for managing national affairs. So 政策 (policy) is involved or included in in 政治 (politics).

Consider the example of Mao Zedong's well known statement "*Lun zhengce*" (On Policy). This internal Communist Party of China (CPC) directive was written on behalf of the Central Committee, following the consolidation after the Long March (1934-1935) and formation of the Second United Front between the CPC and Chinese Nationalist Party (Kuomintang or KMT) to resist the Japanese invasion. It was published on December 25, 1940, in order to provide guidelines for CPC activity under new conditions. "On Policy" first identifies ten ways in which the CPC seeks "to combine alliance and struggle" and then goes into more detail with regard to labor policy, land policy, tax policy, anti-espionage policy, economic policy, cultural and educational policy, and military policy. The overall tone seeks justification as correct analysis, although the text also suggests that the policy is ultimately subordinate to and a means to the exercise of political power.

The term "science policy" is 科学政策 (*kexue zhengce*), which can also be rendered as "scientific policy." In common usage, *kexue zhengce* means "scientific," "right," or "correct" policy as well as policy having to do with science. As policy related to science it can refer to how science is to be viewed as developed from the national level or using political power to accelerate science or how science is to be used in national development. But in this second sense, the term 科技政策 (*keji zhengce*, science and technology policy) is much more common.

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Chapter 22
The Dao of Chinese Water Management and Development: Challenges and Perspectives

Wim RAVESTEIJN

Abstract As the global community addresses the necessary transitions that are required to create sustainable water management and development practices around the world, an examination of the Chinese water tradition, with both its Daoist and Confucian approaches, offers new insights and understanding about the cultural and social embeddedness of water traditions. By comparing current water management practices, such as Integrated Water Resources Management that was co-developed in twentieth century Netherlands, with historical Chinese approaches, a nonlinear form of change that is significant for water policy and transition studies in general becomes clear.

22.1 Introduction

The world faces many serious water challenges and must reflect on sustainable alternatives to current approaches and views, particularly in poor countries and those with emerging economies. China is an example of a country that faces severe water issues. Water resources are scarce: China has 7% of the world water resources but 20% of world population. At the same time, the country is faced with increasing water pollution and the degrading of aquatic environments along with severe flooding problems. Rapid urbanization, industrialization, and economic development in general increase water stress. China has addressed sustainability issues in other related areas, such as energy and urban planning, through wind and solar energy technology development and eco-industrial parks, cities, and ports (Global Wind Energy Council 2010; Liu et al. 2010; Geng and Doberstein 2008; Qiu 2009; Wu 2012; Joss et al. 2013). The question is whether China will also show this vision and active commitment in water management and water resources development as it adapts to meet present-day challenges, particularly in terms of flood control.

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Given the international exchange of scientific knowledge and technology in water management and development, comparisons between various perspectives are used in this paper, particularly the differences in Western and Eastern approaches. The Netherlands provide a European case study to contrast against the Chinese and their water engineering tradition with its Daoist and Confucian roots. These philosophic backgrounds are also analyzed against the current Chinese emphasis on large technically challenging water projects. This approach, as specified by the sinologist Joseph Needham (1900–1995), demonstrates more clearly the social and cultural embeddedness of water use and development than the Western management and construction approaches (e.g. Both Ends and Gomukh 2005; Kates and Burton 1986). It also helps to better understand the dynamics of water development in China and elsewhere.

The West is typically seen as the leader in the global circulation of water ideas, expertise, engineering, management, financial resources, business practices, and the knowledge of how to transition to sustainability. In contrast, China is typically seen as a country that receives knowledge and expertise from the outside, namely the West. This view has become internalized within China as demonstrated by the opening of its market and policy reforms that began at the end of the 1970s (e.g. De Jong et al. 2002, 2007). This paper examines what lessons can be learned from the Chinese water tradition through reflection on water management, development, and its associated problems, arguing that these insights are also significant for global water engineering and management.

22.2 Contemporary Water Challenges and Transitions

The global community faces many water challenges. The three most serious are water shortages, pollution, and flooding. A third of the world population suffer from water shortages (International Water Management Institute 2013) and estimates are that by 2025 two-thirds will be affected (UNEP 2006). Pollution is thought to be the leading cause of deaths and diseases worldwide and more than 14,000 deaths daily (Water Pollution 2013). And more than half the world's population and more than 80% of cities are found in deltas prone to flooding from the sea or rivers (e.g. Fresco 2008). Economic development and increased urbanization, along with global warming, cause and increase these problems. Additionally, besides threatening human lives and health, there are social justice issues around an increase in the unequal distribution of water problems, such as scarcity, pollution, and flooding, with a greater impact on the poor.

Combatting these challenges requires a change in how water resource management and development are approached, often described as transitions (e.g. Geels 2005; Geels and Schot 2007; Berkhout et al. 2004; Smith et al. 2005; Sachs 2008). From a theoretical standpoint, transitions require both system and regime changes with all relevant stakeholders included in the process. Simple transition models emphasize the importance of clear goals and implementation strategies, along with effective technologies and finances (Sachs 2008). A visualization in the form of an S-curve fits in with such a model (Martens and Rotmans 2002).

The social and political contexts affect the form that a transition takes, with the same goals reached in different ways. Transitions can be purposely initiated by central government authorities or business leaders, or they can spontaneously emerge from grassroots efforts or on the shop floor in a bottom-up rather than top-down approach. Other considerations are determining where resources will come from, such as financial means, expertise, mobilizations efforts, etc. (Berkhout et al. 2004). These factors give rise to four different types of transitions:

1. Reorientation of trajectories: e.g., the installation and use of small scale combined heat and power generation in the horticulture sector in the Netherlands.
2. Endogenous renewals: e.g., capture and storage of CO2.
3. Emergent transformations: e.g., the adoption of all sorts of information technologies in offices.
4. Purposive transitions: e.g., the transformation of Dutch households and industries to a gas fired heating system (Smith et al. 2005).

These pathways might involve several coordination mechanisms, like command and control, market mechanisms, and the dynamics of technology. And each of them requires special policy and management tools for intervention, including Triple Helix, Constructive Technology Assessment, and Strategic Niche Management (Ravesteijn et al. 2011).

When it comes to the required water transitions, the question is: how to transition to safe, efficient, environmentally sound, and socially just water systems and control? This transition requires an integrated approach that serves a variety of functions and is based on a variety of values. In addition, it is essential that a non-structural approach replaces a structured approach with a move away from construction toward water management. Planning and policies must be decentralized and approaches from the bottom up used. Participation by a wide range of social stakeholders must be developed, transitioning from the idea of government to one of governance (Ravesteijn et al. 2011; cf. Hoekstra and Huynen 2002).

These transitions assume different shapes depending on the societal context. Sometimes top-down solutions are favored, as in China, while sometimes bottom-up approaches are better, as often used in Western countries. This societal influence will become clearer in the discussion below. It is, however, important to notice that transition theory is specific enough to be applied in diverging socio-cultural settings. Though this theory acknowledges that, in reality, transitions can display a mixture of trajectories that occur simultaneously or over the course of time, one problem remains: in all the models, simple or sophisticated, linearity is presumed. This part of the theory will be confronted with the examination of the Chinese history and practice of water engineering and management.

22.3 Contemporary Water Management and Development Trends

There are three important transformations currently taking place in water management and development that must be addressed in order to confront global water issues (Ravesteijn et al. 2002). One, decision and policy making are shifting to higher levels, while the scale of operations in increasing, resulting in progressively larger works. Two, a change in the emphasis from constructing water works toward management of water flows is occurring. And third, a shift away from a control regime to adaptive water engineering and management is taking place.

Integrated Water Resources Management (IWRM) was developed in the third quarter of the twentieth century in the Netherlands, and Integrated River Basin Management (IRBM) dates back further (Kates and Burton 1986). The idea was created by American geographer Gilbert White (1911–2006) based on a worldwide inventory of knowledge, experiences, and practices. The Tennessee Valley Authority (TVA) in the US was a pioneering and internationally followed example after its creation in 1933, and IRBM, with an emphasis on management, became the dominant water regime in the Western world. The European Water Framework Directive (WFD) that was adopted in 2000 by the EU became the first in a series of directives that has been replicated in other non- European countries, such as Turkey, India, and China (Ravesteijn et al. 2009). The WFD reflects current trends towards increased centralization of management, but is also participatory in its inclusion of stakeholders (Europe Environmental Agency 2009).

The Netherlands water tradition has embraced IRBM. As a historic delta country, the Netherlands has suffered from flooding and has been a contributor to water development globally. Recently, other water issues have arisen in addition to flooding, such as pollution and water shortages during particularly dry periods of the year. Flooding still remains a threat and climate change, which leads to worldwide rising seawater levels and changes river discharge patterns, is an essential part of the problem. Though population growth and economic development are less pressing than in the developing world, they are also important factors in the Netherlands.

Historic Dutch responses (Disco and Van der Vleuten 2002; Ravesteijn and Kroesen 2007) included the introduction of government Water Boards to manage water use and problems, which go back to 1000 AD. Around 1800, the Water Boards were combined with a new National Water Agency to tackle flooding from large rivers like the River Rhine and the River Meuse. Larger scale engineering projects grew over time, such as the construction of the IJsselmeer Dam to close the Southern Sea, the subsequent construction of polders in the new Lake IJsselmeer, and the famous Delta works, including the Eastern Scheldt and Maeslant storm surge barriers. Over time, the Water Boards diminished and were replaced by IWRM, which emerged around 1980. European cooperation and coordination evolved into the WFD in 2000, as the large rivers, particularly the Rhine, became problems once again, possibly due to climate change. The WFD uses a negotiated approach of building water systems in conjunction with communities and small-scale initiatives, for example in Bangladesh (Ravesteijn et al. 2011).

New guiding principles are developing not just in the Netherlands, but around the world, including programs such as Room for the Water and Virtual Water Trade. These programs focus on water usage involved in growing and producing crops and products and seeks to optimize water use in relation to local conditions (Ravesteijn et al. 2011). New developments to address contemporary water challenges will require more targeted and coordinated efforts to reach the desired goals, especially with various transition trajectories. How does China fit in with all the global and local developments in the water domain?

22.4 Chinese Water Management and Development

As with other countries, China faces problems with water management, but in its own unique set of economic, social, and political conditions. While it has scare water resources, China faces pressures from rapid urbanization, industrialization, and development that result in expanded pollution, degraded aquatic ecosystems, and severe flooding. Like other nations, climate change is another factor that could aggravate flooding and other water related problems.

The structural approach is still dominant in China, as seen in the large scale building projects like the Three Gorges Dam and the current South-North Water Transfer plan to move water from the wet south to the dryer north. The transfer plan uses three routes, including the Grand Canal, and social issues like resettlement are part of the socio- technical aspects of the project. IRBM is increasingly used to contend with the issues. The Yellow River basin uses WFD (Ravesteijn et al. 2009), and Integrated Water Management was part of the 1988 Water Law and 2002 Amended Water Law, which combined both IWRM and IRBM. Stakeholder inclusion and engagement has been low but is increasing (Song et al. 2011), and Room for the Water projects are being introduced and have been used for restoration of wetlands in the northern Songhua River basin (Song et al. 2010; Zheng et al. 2014).

There are many challenges to implementing IRBM in China, including water laws that are not enforced, overlapping and uncoordinated water management institutions that are fragmented (see Fig. 22.1), and top down approaches with a lack of public participation and transparency (Song and Ravesteijn 2011). Transitions in China should include goals emphasizing management of water resources rather than construction, greater stakeholder inclusion and a comprehensive strategy that considers social and environmental aspects, as well as a shift to water conservation in production modes and lifestyles.

Chinese history includes many impressive water engineering projects, such as the Grand Canal for transportation of both food and soldiers. While the canal was supposedly started 2500 years ago, the Chinese management of water dates back to Yu the Great some 4000 years ago. Yu is believed to have successfully solved flooding from the Yellow River, and then created a new Chinese dynasty (Needham et al.

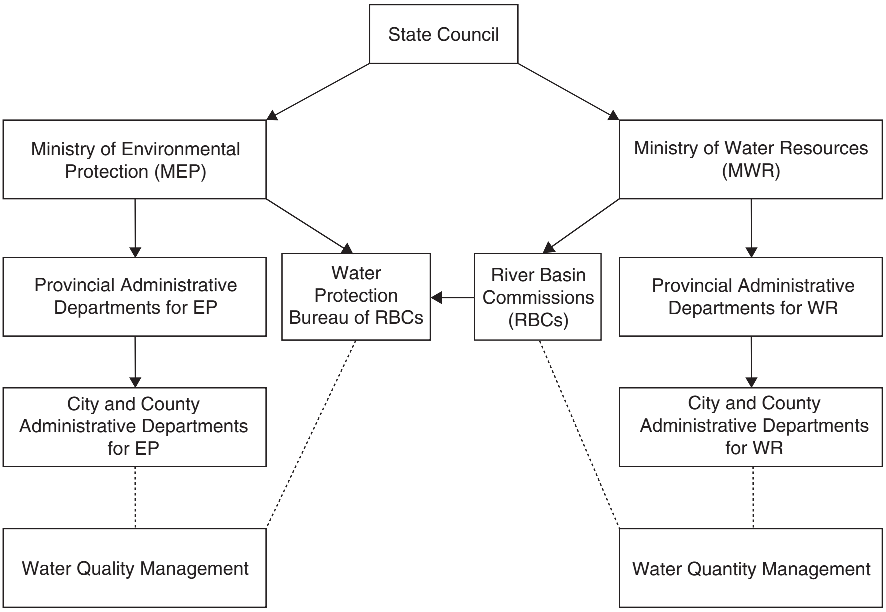

Fig. 22.1 The institutional structure of Chinese water management (Ravesteijn et al. 2009)

1971; Song and Ravesteijn 2011). Following Daoist principles, Yu's approach was to give water its maximum freedom by practicing *wu wei*, which means that no action should be taken to constrain nature, but instead allowing it to takes its own course. Optimal room was given to water flow by setting dykes far apart along rivers and digging deep channels that could be dredged, allowing low dykes. Their efforts resulted in a network of irrigation and shipping channels and retention basins (cf. Lyle 1999).

The opposite approach came later with Confucian engineers, with their *Yin-Yang* philosophy. In contrast to the Daoists' more feminine approach of letting water be free, the Confucians used a more masculine approach to control, confine, and repress water. Large dykes were placed closer together and channels contracted, causing rivers to dig their own beds. Expensive large dam construction was utilized, though it had less social problems associated with it (cf. Dodgen 2001). Engineering and morality, profit and virtue, went hand in hand (Needham et al. 1971). Chia Jang, a Daoist engineer who lived some 3000 years ago, is reported to have said: "those who are good at controlling water give it the best opportunities to flow away; those who are good at controlling the people give them plenty of chance to talk" (quoted in: Needham et al. 1971).

Neither approach completely prevailed, with both having benefits and flaws. Resettlement was a large social issue in the Daoist approach, and sediment that collected in basins tempted farmers and others to colonize the land and risk flooding. The Confucian approach undermined dykes at the bends from erosion and gave rise to unsafe conditions resulting from quickly rising water levels. The result is that

Chinese civil engineering history incorporates the dynamics of both approaches, increasingly resulting in a synthesis of the two. Today in China, the approach to engineering is more Confucian than Daoist, with an emphasis on large scale construction. In terms of the transitions of water management needed, however, a shift that balances and more equally integrates both approaches would introduce a new chapter that can address the high pace of economic development in China, and all the consequences and dynamics connected with it. This renewed tradition could create a facilitating environment for sustainable development trajectories in water engineering and management.

22.5 Conclusions

Innovations in water systems and shifts in water management regimes are necessary for transitions to sustainability to take place, but require more systematic steering. Shifting management to higher levels of authority and increasing stakeholder inclusion presents tensions and challenges. Efforts to reconcile these issues can be seen in the European Water Framework Directive. While China's potential for a transition in its approach to water stress is great, the current emphasis on construction, or Confucian approach, needs to incorporate a more Daoist approach to water management and engineering in order to be balanced; China needs to embrace both of its water lines of action (Li 2008).

The global community can learn from the Chinese water tradition and history. Room for the Water is not new, as Yu the Great and the Daoist approach that began 4000 years ago had the same approach. The relationship between engineering and morality (Van Heezik 2008) is evident in the water tradition of China, with engineering and management embedded in the larger society. The Daoist and Confucian approaches that connect with morality systems can provide an enlightening framework for initiating transitions better understanding, and opening perspectives regarding change and our limitations for intervention in water issues. The Chinese tradition also demonstrates that transitions are not always linear, with flood management approaches moving back and forth and adapting, creating a middle way and synthesis. This cyclical movement is also seen in Dutch water tradition and history. The history of Chinese water interference offers new insights and strategies for solving water problems not only in China, but also globally in policy and water transition studies.

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Chapter 23

Decision Making in the 120MN Shanghai Hydraulic Forging Press Project: Walking a Tightrope Between Politics and Technology

SUN Lie 孙烈

Abstract The successful manufacture of the 120 mega newtons Shanghai Hydraulic Forging Press (SHFP) in 1962 has been considered a typical example of modern Chinese industry and the development of local technology. Actually, it was neither a victory of the Great Leap Forward campaign nor a product of so-called indigenous methods. Taking into account the technical process and decision-making during the project, it is hard to interpret the success of the SHFP as either Mao's "politics in command" or technological determinism. The project, in fact, largely depended on a series of appropriate decision-making and prudent risk analysis by Shen Hong, the chief engineer, who successfully adopted a strategy to maintain a careful balance between technology and politics.

23.1 Introduction

After 4-years of preparation, the Shanghai Hydraulic Forging Press (SHFP) was the first Chinese made heavy forging press with a nominal pressure of 120 mega newtons (MN) put into production at the Shanghai Heavy Machinery Plant in 1962. This massive machine, more than two stories tall, soon became a significant piece of technical equipment for the Chinese manufacturing industry. It was also regarded as a hero, or even a "superstar", in popular culture, and was the subject of books, articles, paintings, and movies (Jiangnan 1965; Lin 1965, 1989; Shang 1977). Some of the more famous creations, include Shanghai TV's video *Wandun-shuiyaji de wenshi* [Coming-out of the 120MN hydraulic-forging press] (1965), The Central Newsreels and Documentary Film Studio's Wandun-shuiyaji [120MN Hydraulic Forging Press] (1966), Shanghai Animation Film Studio's *Wandun-shuiyaji zhan'ge*

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[War song of 120MN hydraulic forging press] (1972), and Xie Zhiguang's painting *Juren zhan qilai le* [Giant has risen to its feet] (1964). Thousands of Chinese and hundreds of foreigners were invited to visit the machine after its construction. In 1 day of 1965 7700 persons, including dozens of foreigners, visited the machine (Shang 1965).

It may seem strange that the Chinese celebrated the SHFP during recent decades, considering that it was the 21st forging press in the world with a capacity of over 100MN. The first press was erected in Pennsylvania at the Bethlehem Steel Company in 1893, and another by the German Krupp Corporation of 150MN in 1928. At least two reasons help explain the special popularity in China.

Firstly, the SHFP was seen as a technological marvel in China at the time. It was not only the largest forging press that the Chinese had ever manufactured but was regarded as an incredible engineering feat, since prior to its construction Chinese engineers had only constructed a much smaller model based on an old British 25MN forging press. People were amazed not only that it was such a useful machine, producing many key heavy forged components, such as large-sized generator shafts, marine crankshafts, rolls for hot or cold mills, artillery barrels, hydrogenation reactors and pressure vessels for nuclear reactors, but that the project to create it had been so successful. The project itself demonstrated that Chinese engineers could work successfully under difficult conditions. Its design and manufacture were quite distinct from other heavy-duty hydraulic presses of the day. Because of this, the SHFP was seen as a prominent milestone in the development of Chinese industry and technology, which had turned from copying to self-designing and self-manufacturing.

Secondly, the SHFP was a symbol of successful politics during a difficult period. The project started in 1958 as a component of the Great Leap Forward campaign (1958–1962). The campaign was launched by Mao Zedong, who believed that in order to successfully create a communist society it was necessary to industrialize and collectivize agriculture with great speed, with a goal of quickly surpassing Great Britain and the United States. During this rapid effort, China suffered from material shortages, economic dislocation, and famine. Because of the difficulties in these other areas, the SHFP became a rare example of success which Mao and Chinese government needed to support the Great Leap's rationality. The early stage of its use further coincided with the Cultural Revolution (1966–1976). Over nearly 20 years, the strategy of developing the economy and industry was based on Mao's "politics in command". Besides the disordered domestic situation, China failed to develop normal relationships with the USSR and USA during this period, with the Chinese running the entire project by themselves. The most important factor for the project was that it was approved directly by Mao Zedong. That is to say, its success or failure would reflect on the leadership at the highest levels. Compared to the many failures of the same time, the success of the SHFP project seemed especially surprising. As a result, the government wanted the SHFP to play a role in influencing people's opinions about China, demonstrating for instance that the Chinese had the ability to achieve their objectives by themselves, even without assistance from the USSR or USA.

In other words, at the beginning of the project, both technological risk and political risk were inevitable. It would not be easy to avoid them. However, Shen Hong (1906–1998)– who was a native of Xiashi, Haining, in Zhejiang Province, had been chief engineering at the Chafang Arsenal in Yan'an, where the Communist Party of China (CPC) had its headquarters from 1938 to in 1948, and who joined the Party in 1947– persuaded Mao to approve the project. Shen Hong was a mechanical engineer and a leader in China's machinery industry. Though he was a self-educated engineer who never went to university, Shen had a major influence on the development of the machinery industry in China. He was in charge of R&D for some large-scale equipment that was completed in China, such as the 120MN SHFP (1962), the 2800 mm hot mill (1972), the 2800 mm cold mill (1972), and the 300MN die hydraulic forging press (1973). Shen was editor-in-chief of the ten-volume *Electrical Engineering Handbook* (1980) and the 15-volume *Mechanical Engineering Handbook* (1982), and served as Vice-Minister of the Ministry of Machine-Building Industry (1961–1982). He was made an Academician of the Chinese Academy of Sciences (1980) and was internationally recognized as an Honorary Member of the American Society of Mechanical Engineers (1980). For Shen, the SHFFP was the starting point of his industrial career in the new political climate. He and his team, whose members had never before designed any heavy machinery, accomplished the task after considerable delays and deadline extensions, despite the political pressure. Furthermore, the machine was manufactured with a unique process that had not previously been adopted anywhere in the world to make heavy hydraulic presses. An examination of Shen's engineering decision making can thus provide insight into the practice of engineering, especially under the unique circumstances existing in the country after the establishment of the People's Republic of China.

23.2 Seizing Opportunity: Shen's Proposal and Mao's Approval

At the Second Session of the Eighth Communist Party of China's National Congress (SSECPC), which convened in 1958, Shen Hong wrote a letter to Mao Zedong that put forward a proposal for developing a 100MN hydraulic press in Shanghai. Mao praised Shen and approved the project.

Before Shen's proposal, the decision-makers in China's industrial sector and some engineers had already known of the need for heavy hydraulic presses. In the 1950s and 1960s, the Chinese government gave priority to developing heavy industry. As a kind of key piece of technical equipment, the heavy forging press naturally attracted their attention. However, they were aware of the limited technical ability and poor industrial infrastructure in China at the time. It was thought by many to be more realistic to buy a 100MN press rather than designing and constructing one by themselves. In fact, most experts were convinced of the need for collaboration with the Soviet Union and some Eastern European countries. With the benefit of technology transfers from the Soviet Union and Eastern Europe to China after 1949, the Chinese had acquired considerable industrial equipment and new technology, the use of which began to encourage them to believe that they might also be able to manufacture other equipment on their own in steady steps. For example, in 1958 the Chinese obtained double 12.5MN, 30MN and 60MN presses from Czechoslovakia. The same year, Russian experts helped Chinese engineers manufacture a 25MN press based on an old British model. Consequently, decision makers proposed to manufacture their own machines step by step: a 30MN press in the Second Five-Year Plan period (1958–1962) and a 60MN press in the next period (Zhongxing 1958).

However, the rules of the game were radically altered because of the SSECPC. In the session, Mao put forth a radical strategy of economic development based on his political ideology. He criticized and expressed dissatisfaction with those who had so-called "blind faith" in needing outside help and were fearful of attempting to create technology domestically. Concerning the development of industry, Mao said sarcastically that some thought development would be too difficult for China on its own and that it must depend on the Soviets for help. By contrast, he called attention to people who should be taken as models for Chinese communist creativity. First of all, of course, Karl Marx, but then the Russian pioneer rocket scientist theory Konstantin Tsiolkovsky (1857–1935). Additionally, there were the Chinese scientists Chen-Ning Yang and Tsung-Dao Lee, who had recently been awarded the 1957 Nobel Prize in Physics, and Hua Luogeng (1910–1985), a mathematician known for his contributions to number theory, and others (Zhonggong 1992). Mao wanted China to become more self-reliant and take a leadership role in the historical development of communism in the form of what would soon become the program of the Great Leap Forward.

Shen Hong judged that this was a just right moment to propose the SHFP project. Earlier it was a domestically constructed 100MN hydraulic press that had been his dream. As the Vice-Minister of the Ministry of the Coal Industry of China, Shen attended the SSECPC. The difference between him and other CPC leaders was that Shen had extensive experience in machine manufacturing. As a young man in Shanghai, he had become attracted to engineering. During the Second Sino-Japanese War (1937–1945), he served a term as the chief engineer of an arsenal to design machines and military devices for the CPC army. He quickly assumed an even larger role as an influential technical expert in the CPC. While managing the importation of machinery from the USSR in the 1950s, he investigated a large Russian hydraulic press.

In his letter to Mao, Shen mentioned his experience in the Soviet Union. He wrote, "After I saw the 100MN hydraulic press at Uralmash, I thought we should build a 100MN one in Shanghai. I believe we can do it independently." He also agreed with Mao's speech regarding blind faith in needing outside help and fearing the Chinese ability to construct its own press. "As for the machinery industry, once the three words – large-scale, accurate, and complicated – are talked about, many people become frightened", reflecting an attitude of adoring the Soviets and obeying Russian experts. At the end of the letter, he indicated it would not be difficult to carry out the project. “It will take one year or a year and a half to achieve the engineering task. This 100MN hydraulic press will be used for ten years, even though it will probably be not a perfect one” (Shen 1986, pp. 1–2).

There is no indication that Shen purposely underestimated the difficulty of the project. Undoubtedly, his expert status and political attitude appealed to Mao. The letter was listed as a formal document of the SSECPC so that other participants could read it and recognize its importance. Mao valued Shen in the session and instructed the leaders of Shanghai to assist Shen in the project. The supreme leader had approved the SHFP project.

23.3 Careful and Venturesome Decisions on Design and Construction

In any engineering project, it is not wise to replace technical rationality with political enthusiasm. Although he had Mao’s endorsement, Shen remained sober with regard to the technical challenges of the SHFP project.

After the SSECPC, Shen went to Shanghai in June 1958 as chief engineer for the SHFP project. The leaders in Shanghai promised to coordinate with him. The first need was to organize an engineering team. Shen chose each member personally. The most prominent members were Lin Zongtang (b. 1926) and Xu Xiwen (b. 1935). Lin graduated from the Department of Mechanical Engineering of Tsinghua University (1949). He had translated a Russian book about high-speed cutting into Chinese. During the 1950s, he was the Vice Director of the First Machine Tool Plant in Shenyang. After the SHFP project, Lin became the Engineer-in-Chief of the Shanghai Heavy Machinery Plant (1962–1978) and later was placed in charge of the Beijing Electron Positron Collider project. Still later he became Head of the Ministry of the Aerospace Industry (1988–1993). Xu had graduated from the Department of Mechanical Engineering of Dalian Institute of Technology (1955) and earned a Master of Science degree from Shanghai Jiao Tong University (1957), after which he worked at Jiangnan Shipyard until 1962. After the SHFP project, he became the chief designer of the 2800 mm cold mill project (1964–1972) and later the Engineer-in-Chief of Shanghai Heavy Machinery Plant following Lin (1978–1994). When the SHFP project began, the two young mechanical experts had one thing in common: they had never personally seen a hydraulic press. As far as Shen was concerned though, they were bold enough to meet the technological challenge.

One of Shen’s bolder choices was picking the Jiangnan Shipyard to undertake the press construction task. Shen intended to make the hydraulic press in Shanghai, but none of the facilities there had ever produced that large a machine. He made his decision after comparing different locations. What convinced him were two major factors: the shipyard’s greater technical strength and its wider experience in manufacturing. Since its founding in 1895, and was attached to the Jiangnan Arsenal until 1905, the Jiangnan Shipyard had become one of the largest and most advanced in China. It was the earliest modern enterprise in China and during the 1950s the largest plant in Shanghai. The shipyard had constructed a number of large ships, including four transport ships for America over ten thousand tons, which were named the Cathay, Celestial, Oriental, and Mandarin (Xin 1999, p. 16). During the 1950s, several large vessels and submarines were also constructed at the shipyard. Most importantly, it had both the personnel and equipment necessary, including qualified engineers, laboratories, and skilled workers. Regarding the reasoning behind the choice, Shen said, "I chose the Jiangnan Shipyard because it has many old workers and powerful technical strength" (Shen 1986, p. 4). The sentence was somewhat political for "old workers" were given a high political status at that time, and, in fact, the word strong had connotations in Chinese. However, politics was not capable of describing technical principles, let alone the details of design and construction. Fortunately, when Shen analyzed the technical problems, he carefully put politics aside.

At the beginning of the design phase, Shen realized that he needed to acquire some essential information. He knew that in China most detailed technical information about hydraulic presses usually came from Russian books, magazines, artifacts, and drawings. Shen decided to collect all this information even though in his letter he had supported Mao's criticism of adoring the Soviet Union. He and his team spent 3 months gathering materials and doing research. They visited all domestic workshops equipped with hydraulic presses. Through measuring, photographing, copying drawings, and interviews, they collected a large amount of data. They also found some useful Russian, English, and German books. This information indeed played a crucial role in the design of the SHFP. In Shen's opinion, the most significant references were two books: a Chinese version of a Russian encyclopedia of machine construction (Situoluorefu 1958) and a German book on the design of high-pressure components (Müller 1952). "We designed the SHFP from them" (Shen 1998, pp. 17–18). His team also referenced others foreign books including English books (Sun 2011).

However, the SHFP was no direct imitation of other hydraulic forging presses. Its technical particularity was its all-welded construction. That is, all of the massive parts (three beams, four columns, and six operating cylinders), each of which weighed from 90 to 250 tons, consisted of several small parts assembled by welding. Other large hydraulic presses were constructed from built-up beams, single-piece forging columns, and cylinders. For the SHFP, it was impossible to adopt the ordinary method, which depended on the availability of large casting and forging equipment, large machine tools, and large steel heating furnaces, none of which were present in the Jiangnan Shipyard or elsewhere in Shanghai. Shen and his colleagues thus had to find another construction method. After a series of calculations and experiments with material properties and manufacturing processes, Shen and his team decided to use this particular all-welded construction, despite lacking experience and there being no precedent. They realized that it would be the biggest technical risk of the entire project. When Shen put forward the proposal to Mao, he could never have imagined that the project would face such a difficult operation.

Shen and his team found a way to construct the all-welded components by means of an electro-slag welding process and a particular machining method they called “ants gnawing bone”. Electro-slag welding was useful especially for thick materials. The benefit was that it could produce the largest components without the typical large industrial equipment that was necessary. It came from the Paton Institute in the USSR during the 1940s, the process and equipment for which the Chinese imported in the 1950s as a means for the manufacture of other heavy machinery. At the Jiangnan Shipyard, Shen instructed engineers and workers to master the process. They also constructed several special-purpose welders specifically for the SHFP project. In the Soviet Union, large welded components were usually cut by large machine tools. In China, the components were manufactured with the “ants gnawing bone” method, which could cut the material into the final shape and size by “ants” – movable small machine tools – working in small steps. In other words, small machine tools could be employed to manufacture larger components. The Chinese regarded this method as an indigenous technology. The disadvantages were its inefficiency, low- quality, and dependence on the operator’s experience; but it worked.

Facing numerous technical difficulties, Shen was not able to meet the construction timeline he had promised Mao. According to Shen’s original plan, the project would be completed within a year to a year and a half. But it took more than a year just to come up with a complete design and unsurprisingly the engineering team decided they needed to construct two smaller models of the SHFP to test the design. One was a 12MN hydraulic press, which was tested for a year before SHFP construction. The other was a small 1.2MN press that was used to research its structural and material properties. Meanwhile, workers practiced the electro-slag welding and “ants gnawing bone” processes. Not until these processes were mastered, did Shen approve construction of the actual SHFP. Even so, it took 300 workers 8 months to carefully make the components and 98 days to cut the four welded columns (Shen 1980, pp. 234–235).

While working out the engineering a visiting Russian expert criticized their designs and plans. Shen nevertheless encouraged his colleagues: “we should not accept the bondage of the experts. The central authorities approved the project. Nobody can oppose it” (Shen 1986, p. 3). Yet his confidence was based not just on political support but on their 4 years of work devising and mastering the necessary technology.

23.4 Reliable and Artful Decisions on Process Control

Process control can determine the success or failure of engineering projects. Shen Hong paid great attention to this principle. For him the difficulty of the SHFP project lay in deciding whether the technological requirements would have priority over the political.

To maintain the quality of the engineering, he refused to rush the job. As previously mentioned, Shen prolonged the design phase by almost 2 years in his persistence in experimenting and testing, including the two prototypes. What is more, several times he resisted pressure from political leaders in Shanghai to speed up the timeline in order to make the project into a political gift at the expense of quality. In a letter to Qian Min, Director of the Shanghai Industry Council, Shen wrote, "the machine should be used at least for fifty to one hundred years. Regarding the long-term investment, if the machine would be made only in three or five months, it is hard to avoid slapdash activities and shortening its working life" (Shen 1986, p.5). He also wrote another letter to Chen Pixian, the Deputy Party Secretary of Shanghai, to insist on his view that "sufficient time would be more profitable to manufacture the hydraulic press" (Shen 1986, p. 6). Maintaining process control, Shen personally drew up the construction and installation schedule in order to make sure that everything went according to plan.

At the same time, Shen used politics to his advantage, relying on his political influence to ensure that the engineering could proceed smoothly. In 1960, he received news that the SHFP was likely to be abandoned because of severe economic problems in China. Instead of quitting, however, he immediately appealed to Premier Zhou Enlai for help. Zhou was an important figure in the CPC, second in influence only to Chairman Mao from 1949 to 1976. On the basis of Mao's previous support for the project, Zhou not only gave the order to continue but also made an investment of RMB 8 million for the engineering (Shen 1986, p. 268). Zhou further told Shen, "You can directly come here and get help when you have difficulties" (Lin 2006, p. 5).

In further efforts to garner political support a number of other key Chinese political leaders were invited to visit the work site. These included Liu Shaoqi (, the President of China, 1959–1968), Zhu De (Vice-Chairman of the CPC, 1956–1966, and Vice-President of China, 1954–1959), Chen Yun (Vice-Chairman of the CPC, 1956–1969, and Vice-Premier of China, 1949–1975), and Bo Yibo (Vice-Premier of China, 1959–1975). Such a powerful contingent of CPC cadre could not help but provide useful political cover for the delays that were necessitated by the engineering challenges.

23.5 Conclusion

A good decision maker must maintain a balance between politics and technology when both have significant impacts on an engineering project. Any decision that takes only one side into account and neglects the other will lead to failure, so finding the proper balance between the two, as Shen Hong did, is crucial to managing a successful project.

During the Great Leap Forward, most industrial projects failed because their decision makers overemphasized political factors at the expense of properly prioritizing scientific and technological principles. Shen's success started with the proposal of the SHFP project, which not only met practical technological needs but was also in accord with political directives. After seizing the political opportunity, he conscientiously made decisions based on technical requirements while continuing to seek political approval. The all-welding construction process, which was a novel combination of foreign technology and local methods, was also useful for political reasons. Because it was not just a copy of Russian technology, it won favor with Mao and other politicians.

Decision making is usually a dynamic process between technology and politics that depends on the level of importance and specific characteristics of the project. Technical matters should be solved with technical expertise, and political issues with political prudence. In practice it is often hard to separate the two and "Give to technology what is technological, and to politics what is political." Shen worked hard to keep a subtle balance and an essential tension between the technological and the political, rather than leaning too far to one side or the other. When he made decisions, sometimes he insisted on giving priority to the technology, and sometimes he sought political support, maintaining a careful and artful balance.

For a decision maker, the SHFP project is an inspiring case that demonstrates the difficulties and the possibilities in an engineering project. Before the establishment of modern risk assessment systems, Chinese decision makers in major projects like the SHFP had to carefully walk a tightrope between technological possibilities political pressures. Indeed, it is not clear that any risk assessment system could do as well as an engineer such as Shen Hong, who was able to rely on his own good sense in both the technical and political spheres.

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Part V

Supplement: Two Interviews with Influential Chinese Philosophers of Engineering and Technology

Chapter 24
Roots of the Philosophy of Technology in China

YUAN Deyu 远德玉, CAO Dongming 曹东溟, Carl MITCHAM, and YIN Wenjuan 尹文娟

Abstract An engineering colleague and collaborator of Chen Changshu, who has been called the founder of contemporary Chinese philosophy of technology, Yuan Deyu recalls early efforts to develop philosophy of technology that took place at Harbin Institute of Technology in the 1960s. Case studies based in the idea of learning from workers and frameworks adapted from Japanese theory of technology scholarship constituted the original philosophy of technology in contemporary China. The importance of this work is largely unknown in the West and even among Chinese scholars born after the Cultural Revolution. Against this background, Yuan questions many of the ways Chinese philosophers have tried to adapt or relate to Western studies in philosophy and technology.

24.1 Introduction

What follows grew out of an extended conversation between Yuan Deyu, one of the early researchers in philosophy and technology studies in China, and Carl Mitcham, a historian of philosophy and technology studies, as arranged and facilitated by Cao Dongming and Yin Wenjuan, two members of the faculty at Northeastern University in Shenyang, China. The discussion began with a May 5, 2015, letter from Yuan to Mitcham, in which he raised a number of questions about relationships between his and Mitcham's approaches to the philosophy of technology.

In discussion with CAO Dongming 曹东溟, Carl MITCHAM, and YIN Wenjuan 尹文娟

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After expressing concern about the way "Chinese philosophers of technology focus so much on the translation of Western philosophical views about technology and the writing of irrelevant articles influenced by the ideas of foreigners that lack philosophical reflection on the reality of technological development in China," Yuan Deyu identified five issues that he would like to discuss:

- First, whether concepts in Western philosophy of technology are adequate for understanding the Chinese tradition in the philosophy of technology.
- Second, the historical origins of Chinese philosophy of technology.
- Third, different approaches to doing research in the philosophy of technology.
- Fourth, the experience of managing technology in China and its problems, and whether there is need for an "empirical turn" in Chinese philosophy of technology.
- Fifth, challenges facing the future of the philosophy of technology in China.

Mitcham responded on June 17, 2015, with an expression of hope that the two could meet during the biannual international meeting of Society for Philosophy and Technology that would be hosted by Professor Chen Fan and Northeastern University, July 3–5, 2015. After noting that he had been introduced to Yuan Deyu's work by "scholars such as Wang Qian (Dalian University of Technology) and Li Bocong (University of the Chinese Academy of Sciences)" and that younger scholars such as Yin Wenjuan, Zhu Qin, and Wang Nan had also called attention to his influence, Mitcham added brief comments on the five issues:

- Different views about technology: I very much agree with you that there are important differences between China and the West in the understanding of what technology is.
- Origins of philosophy of technology in China: As a historian of the philosophy of technology, I especially look forward to learning more [on this topic].
- The differences between practical (bottom up) and more theoretical (top down) philosophical approaches to technology are important. This is a topic which, like all the others you mention, deserves considerable reflection.
- Like you, I am not sure there is need for an empirical turn in Chinese philosophy of technology. Actually, I am a little skeptical of all the "turn-talk" that is currently so popular in the philosophy of technology.
- Yes, there has been a good deal of imitation of the West in many fields of Chinese scholarship. For myself, I am interested in trying to think a "normative reversal." Instead of looking at the West as a norm and noticing what China lacks, I want to try to take China as a norm and ask what is missing in the West.

The meetings took place on July 4 and 7, 2015, and involved extended exchanges about the roots and character of philosophy and technology studies in China. Cao Dongming and Yin Wenjuan were full participants in the discussion; then drawing on the initial letters and the recordings, worked with Yuan Deyu and Mitcham to edit this text.

Yuan Deyu, who was born in 1934, has from the 1960s been involved in issues concerning technological development, and is thus someone well qualified to comment on it. Three of his books (co-authored with others)—论技术*Lun jishu*

(Shenyang: Liaoning Science and Technology Publishing House, 1985), 技术选择论*Jishu xuanze lun* (Shenyang: Liaoning People's Publishing House, 1991) and 产业技术论*Chanye jishu lun* (Shenyang: Northeastern University Press, 2005) [English versions of the titles: *On Technology*, *Selectivity in Technology*, and *On Industrial Technology*]—are accepted in China as key contributions to the field. One of his basic theories seeks to understand "technology as process," that is, in terms of the whole dynamic process of its development. This approach leads to a second core idea of "technology form theory", that is, technology presenting itself in different forms in different developmental phrases, which explains how there can be different but related definitions of technology. The "technology as process" theory has become an important influence on methodology for many Chinese scholars.

Yuan Deyu is also strongly influenced by Chinese traditional culture, especially Daoism. In Yuan's philosophy of technology, process in technology is analogous to how traditional Daoism conceives relationships among 器*qi* (tools or visible matter), 形 *xing* (form) and 道*dao* (way). Understanding of *dao* cannot be separated from tools or visible matter; *dao* is understood through tools or visible matter. Therefore, existence in process is the *dao* of technology. In other words, time should be introduced into the understanding of technology, because technology is due to the unity of multiple opposing factors in a specific space and time. That is, process is the *dao* of technology, not just the static analysis of artifacts or knowledge.

24.2 Interview

Carl Mitcham: In your letter to me you referred to yourself as a "flying crane" who no longer participates in many academic activities. I love the image. But it makes me wonder about your reason for alighting on the earth again and doing this interview.

Yuan Deyu: The first reason is you. I want personally to thank you for something that happened years ago. You may not remember how you helped Professor Yin Dengxiang publish an English review of two Chinese books on the philosophy of technology, one of which happened to have me as a co-author and the other as a contributor. [See Yin Dengxiang, "Two Recent Chinese Studies in the Theory of Technology," *Research in Philosophy and Technology*, vol. 13 (1993), pp. 373–381. The books reviewed were Yuan Deyu and Chen Changshu, 论技术 *Lun jishu* (Shenyang: Liaoning Science and Technology Publishing House, 1985); and Chen Nianwen and Gao Dasheng, eds., 技术论*Jishu lun* (Zhangsha: Hunan Educational Publishing House, 1987).] This meant a lot to me and my collaborators. It was the first time that Western scholars were able to take note of what we Chinese scholars were doing in the philosophy of technology. According to Chinese tradition, when you are helped by someone, you give sincere thanks before you die, so that you can rest in peace. Although you have visited China many times, it is only now that we are able to meet. Unfortunately, my co-author is deceased and I am the only one left alive, so I want to thank you on behalf of both of us.

CM: I am really happy to have been instrumental in helping call attention to your work. But actually I also facilitated the publication 4 years earlier of a more general English language introduction to Chinese philosophical reflection on technology by Professors Gao Dasheng and Zou Tsing, an article that also profiled your and Professor Chen Changshu's work. [See Gao Dasheng and Zou Tsing, "Philosophy of Technology in China," *Philosophy and Technology*, vol. 6: *Philosophy of Technology: Practical, Historical and Other Dimensions* (Dordrecht: Kluwer, 1989), pp. 133–151.] I would also like to credit Frederick Ferré and Paul T. Durbin, the respective general editors of the two series for which I did the editorial work that led to both publications. Unfortunately, the first one apparently did not reach you, which I regret.

YDY: Yes, I never saw the Gao-Zou article. Nevertheless, additionally, in 1999 Professor Yin Dengxiang mailed me a copy of the Chinese version of your introduction to philosophy of technology [技术哲学概论*Jishu zhexue gailun*, trans. Yin Dengxiang and Cao Nanyan (Tianjin: Tianjin Science and Technology Publishing House, 1999)]. It included an overview of the philosophy of technology in the West, which benefited me a lot. After my retirement, I reread it again. This time a number of questions occurred to me. I would like to understand better your distinction between two traditions in the philosophy of technology—that is, between engineering philosophy of technology and humanities philosophy of technology—and the tension between empirical and theoretical interests. I also wonder about the possibility of comparing your notion of technology as process—which you call one of the four modes of the manifestation of technology [the others are technology as object, as knowledge, and as volition]—and my concept of technology as process. Finally, I wonder why you paid more attention to what you call humanities philosophy of technology than engineering philosophy of technology.

Many Chinese philosophers of technology today are keen to introduce new ideas from Western scholars. Using these ideas they often write unrealistic articles that lack true philosophical thinking about practical technological developments in the Chinese context. Their understanding of history and what happened in Chinese philosophy of technology is far from what I experienced. Recently, for instance, some Chinese scholars have adopted Dutch terminology to talk about an "empirical turn" needing to take place also in China. But if this is what foreign scholars learn about Chinese philosophy of technology, it will give them a distorted picture. Especially since most of my contemporaries are deceased, it is necessary for me as one of the few remaining to record my experience and opinions about all this. My students [Cao Dongming and Yin Wenjuan] have told me that you are a serious scholar who is also easy to talk to, and that you are sincerely interested in understanding Chinese philosophy of technology, so I want to share with you a few personal thoughts, through them as my translators.

CM: I am grateful also for this opportunity to meet with you, and am only sorry that we have not met before—and that I do not speak Chinese. So I also want to thank Cao Dongming and Yin Wenjuan (the latter studied with me for a year in the United States) for facilitating our discussion. This is a rare opportunity for two scholars to reflect together at leisure about something that is important to both of us.

To begin, then, from your perspective, what are the main differences between Chinese philosophy of technology and its Western counterparts?

YDY: The differences are complex, with both Chinese and Western philosophy of technology exhibiting their own distinctive characteristics. One of these involves the nuances of basic terms. For instance, "technology" is translated in Chinese as 技术 (*jishu*), a compound of the two characters 技 (*ji*) and 术 (*shu*). *Ji* literally means skill (技能 *jineng*), technique (技巧 *jiqiao*), and craft (技艺 *jiyi*). There used to be an ancient Chinese saying "craftsmen have their skillful techniques" (工有巧 *Gong you qiao*), which implies that techniques (巧 *qiao*) are technology (技 *ji*). Technique is acquired through repeated practice. *Shu* refers mostly to methods, procedures, processes, and means such as arithmetic (算术 *suanshu*), martial arts (武术 *wushu*), medical skill (医术 *yishu*), and astrology (方术 *fangshu*). *Jishu* normally refers to the practical activities of making and doing by using skills, techniques, methods, means, and crafts.

The English "technology" also comes from a compound: a combination of the Greek *techne* and *logos*, referring to knowledge and research about *ji*. By contrast, in Chinese knowledge about *ji* belongs to the category of science. In the West it was when the emergence of the concept of technology (as in Johann Beckmann's "general technology" [*AnleitungzurTechnologie*,1777]) caught the attention and criticism of philosophers, that philosophy of technology was born. But China has books closely analogous to.

Beckmann's that are much older, such as Song Yingxing's 天工开物 (*Tiangong kaiwu* [literally "Heavenly creations" but often translated as "Exploiting works of nature," 1637]), an encyclopedia of handicraft and agriculture technologies. This book has been translated into many languages, but never caught the attention of Western philosophers.

CM: Can you say a little more about the differences that have arisen out of these different backgrounds in China and the West? What do you see as unique in the Chinese tradition of research in the philosophy of technology?

YDY: First of all, the boundaries among liberal arts, history, and philosophy are not as clear in the Chinese academic tradition as in the West, while it seems to me that in the West philosophy is more closely related than in China to science and religion. What Chinese ancient philosophy pursues is *logos* or reason in human relationships. We have countless inventions, and books exploring the principles of practical science, but the *logos* underlying inventions has not been of philosophical interest. Philosophy has been more concerned with ethical issues. Besides, books involving practical science were always written by those literati [or Confucian scholars] who had been kicked out of the governmental bureaucracy. As for Western philosophy, the *logos* of nature has been a priority, which explains why natural philosophy, which connects philosophy and science, is so well developed. For instance, what Isaac Newton's *Philosophiæ naturalis principia mathematica* [Mathematical principles of natural philosophy] talked about is the science of mechanics in nature.

Second, ancient Chinese scholars believed it was important to act in harmony with heaven or nature, so artifacts made by human beings were called "heavenly creations," even though they are things of and in this world. In Chinese, heaven is not something supernatural; it is part of this world. By contrast, in the West there has been a clear distinction between a supernatural god and earthly human beings, so that human-made artifacts are thought of as separate from heaven. The Chinese do not believe in god in heaven but of god on earth, with the emperor as a kind of image; there are rarely any discussions about the relationship between humankind and god or gods in Chinese philosophy. The "immortals" in Daoism are simply mortal human beings who have achieved a kind of harmony with the *dao*. Similarly the Buddha of Buddhism arises from self-cultivation and the refinement of worldly concerns. By contrast, most people in the West have sincerely believed in the existence and importance of a supernatural god, which is why the human-god relationship has been such an important theme in Western philosophy. (Incidentally, Martin Heidegger is no exception here. His last, posthumously published interview [1976] was titled "Only a God Can Save Us.")

Third, change (易 *yi*) is a key notion in Chinese philosophy. Change emphasizes that things must be understood through their interrelationships and the changes in these relationships. In this respect, the most ancient of Chinese philosophical texts, *Yi jing* [commonly translated as "Book of changes"] is also important. By contrast, what Western philosophy pursues is the normative in what is unchanging or permanent, as in Plato's transcendent forms.

Fourth, theoretical thinking and practical application are not separated or opposed in Chinese philosophy. This is true for both scholars and the common people. There is no spirit of the pursuit of knowledge for the sake of knowledge itself, of the kind that is characteristic of the Western research tradition. Although there exist three different traditions of Confucianism, Daosim, and Buddhism in Chinese philosophy, all are strongly influenced by the Confucian emphasis on the importance of practice and the idea that theory cannot be divorced from practice.

Last but not least, intuitive comprehension or intuitive thinking plays a much larger role in Chinese philosophy than in the West. In the West, rationality and logical thinking tend to be more significant than intuition.

Of course there are many differences between academic traditions in China and the West that deserve attention. But my basic point is that due to both differences between 技术 (*jishu*) and "technology" and differences in philosophical traditions, philosophies of technology in China and in the West have taken different paths.

Chinese philosophers of technology originally began with real-world experiences. They generally attempted to learn technology first, then to analyze and philosophize about it, which obviously shows a strong empirical orientation. By contrast, philosophers of technology in the West originally tended to reflect on and criticize technology based on some already existing philosophical system, thus manifesting a theoretical orientation. As you have emphasized, there is a certain tension between empirical interests and theoretical interests, and I think because of this kind of tension, philosophy of technology in both China and the West could be developed further in ways that might beneficially influence each other.

CM: I really appreciate what you say about Chinese philosophy, especially Confucianism, taking a this-worldly orientation. Your point echoes some of the things I am learning from the work of Mou Zongsan and Li Zehou, who make this same point, although in different ways. Both stress that Chinese philosophy is based in a "one-world ontology," to use Li Zehou's term. In the context of such a one-world ontology, when and how do you think Chinese philosophy of technology emerged? I have heard that it was during the 1980s. But can it be traced back to a specific article or book?

YDY: Philosophy of technology did not begin in China in the 1980s. This is a basic mis-perception that is present even among some Chinese scholars. Philosophy of technology in China began in the 1960s in a very special historical context. What we learned from historical materialism is that if you want to figure out the occurrence and development of something, you have to place it in the social context of its era.

To be more accurate, the development of Chinese philosophy of technology can be divided into two stages: The first stage involved philosophical research on particular technologies, i.e., in efforts to identify general principles of development in particular concrete technologies. The second stage treated technology as a whole, and attempted to explore the general patterns of technological development by viewing technology in its social context. The former stage began in 1960s, before the Cultural Revolution; the latter stage in the 1980s, just after the Cultural Revolution and during the Reform and Opening.

The year of 1958 was special in modern Chinese history. The "Three Years of Natural Disaster" [also known as the "Great Leap Forward"] began in that year along with two kinds of movement: one in technology, another in politics. In technology there were the "Double 革 (*ge*)" movement (for technical innovation and technical revolution) and the "Four 化 (*hua*)" movement (to mechanize, semi-mechanize, automatize, semi-automatize). [The Chinese character 革 (*ge*) is part of both "innovation" (*gexin*) and "revolution" (*geming*), hence the condensed reference to "Double Ge"; and the Chinese character 化 (*hua*) is a suffix in both "mechanize" (机械化 *jixiehua*) and "automatize" 使自动化 *shizidonghua*), thus the acronym-like "Four Huas."] In politics during this period there was also the "average people studying Chairman Mao's masterpieces movement."

President Li Chang of Harbin Institute of Technology (HIT) proposed that these two movements should be combined, since under the guidance of Chairman Mao's thought the "Double Ge" and "Four Huas" movements will find their proper directions. This was the origin of what is also called "natural dialectics" or "dialectics of nature" movement [a term derived from Friedrich Engels' book *Dialectics of Nature*, written in the late 1800s but published posthumously in 1925].

The social context of Double Ge and Four Huas is that in 1958 the Sino-Soviet relationship broke up [in part as a result of Mao's reaction to the death of Joseph Stalin in 1953 and to Nikita Khrushchev's secret denunciation of him in 1956] and all the technical adviser experts from the Soviet Union were withdrawn from China. Domestic Chinese technical experts had difficulty replacing all the lost Soviet technical experts. HIT President Li proposed that studying natural dialectics and Mao's philosophical thought—using them as a means to solve the problems encountered in scientific and technological research—would provide both a new way forward and could strengthen Chinese confidence.

Encouraged by this call, many professors and senior HIT students went to the factories. Applying Mao Zedong Thought on the shop-floor with experienced workers as well as scientific researchers, they aimed to realize the Double Ge and Four Huas movements, while summarizing and enhancing the creativity and experience of normal workers.

In that same year of 1958, a special machine tool modular "building block" process was created in Harbin by some experienced workers. In a factory without any big plant buildings, big machine tools, big cranes, or steel casting equipment, the workers ingeniously used all kinds old technical elements—steel rails, angle iron, plus some specially made parts—to produce 37 different large machine tools, including a lathe, grinders, milling machine, boring machine, drilling machine, and planning machine. This local worker ingenuity solved some crucial problems of not being able to manufacture large work pieces due to a lack of heavy industrial tools.

When HIT President Li Chang learned of this, he sent professors and students specializing in machine-tool design to the factory to learn from the workers. Re-designed and re-manufactured by students and professors, a series of nine "building block" modules were created, which could be ingeniously assembled into 13 standard machine tools. According to President Li, the successful creation of these building block modules was due to the fact that "they grasped the main conflict in machine tools," so "we should analyze the problems encountered in our scientific experiments from the perspective of material dialectics, and start to study and do research in natural dialectics."

At this time, the economist Yu Guangyuan happened to be in Harbin. Yu is the founding father of the Institute of Natural Dialectics in China. He encouraged the scientific and technical personnel to learn and apply dialectics of nature as early as the era of Yan'an [a city in Shaanxi Province which, after the Long March, became the headquarters of the Communist Party of China from 1936 to 1948]. President Li briefed him on the creation of building block module machine tools and emphasized the influence of philosophical thought in this creation, proposing that "applications of material dialectics in production activities and scientific experiments should be a very important aspect in Chinese natural dialectic research." He further argued that Chinese natural dialectics research should not be limited to exploring philosophical issues in mathematics and basic science [as was the case in Engel's natural dialectics], but should also be applied in industrial production and agricultural work. From this conversation, they decided to hold a national natural dialectics conference. After some preparations, in August 1960 the Institute of Philosophy of the Chinese Academy held a meeting in Harbin.

Conference participants included university professors, researchers, engineers, and technicians. They submitted more than 70 papers, demonstrating how natural dialectics research was being extended from basic disciplines such as mathematics, physics, and chemistry to engineering technology, agriculture, medicine, and more. After the conference a reporter from *Guang Ming Daily* asked for something to publish. In order not to reveal critical information, HIT provided only one paper on "Exploring the Principles of Conflict Movements inside Building Block Module Machine Tools," one of the few papers that did not disclose some advanced research work. The paper appeared in a philosophical supplement to *Guang Ming Daily* in November 1960. Together the organization of a national dialectics of nature conference and the publication of this paper clearly indicates that by this point Chinese philosophical research on technology had begun.

A landmark event for the emergence of Chinese philosophy of technology followed when Chairman Mao read the *Guang Ming Daily* article. He wrote a personal letter to the HIT Communist Party of China (CPC) committee indicating that he liked the paper and made suggestions for expanding it to from 15,000 to 20,000 Chinese characters, adding more specific examples, and making it more readable for the masses. He also recommended that the expanded paper be published in *Red Flag*, the CPC theoretical journal. Edited by Li Chang with contributions from factory workers, technicians, and university professors, the article went through numerous revisions and was published in *Red Flag,* issues nos. 9 and 10. [Given the length of this article, *Red Flag* combined No.9 and No.10 into a single publication in 1961.]

At this time there was no leader of any country in the world showing an interest in philosophical research about technology. Given the situation in China at that time, Chairman Mao's interest was not just academic but a major political event. The publication in *Red Flag* had implications for the whole country and further stimulated the development of Chinese philosophy of technology. This event symbolized the full coming to birth of Chinese philosophy of technology. And the research paradigm of building block module machine tools—from the concrete to the abstract—has ever since been a significant influence in philosophical reflection on technology. In order to further promote the nation-wide natural dialectics research, the CPC Party School organized a special training program involving philosophy professors in various universities chosen by the Ministry of Education. The result was to add enormous energy to the research program in natural dialectics.

The reason I spent so much time on the history of this period is that many scholars, especially those born after the Cultural Revolution, know so little about it. But their ignorance distorts Chinese understandings. I personally began to learn natural dialectics and the history of science and technology during that time. Most foreign scholars do not understand what natural dialectics means in China. It is not just a phrase borrowed from Engels but names an interdisciplinary research program that can serve as a big tent for philosophical issues concerning science and technology, on one hand, along with the relationships of science, technology, and society, on the other. The research involves philosophers as well as volunteers with science and engineering backgrounds. The Institute of Natural Dialectics includes research groups from many disciplines such as the philosophy of science, philosophy of technology, philosophy of engineering, science of science, philosophy of ecology, and more.

CM: How did philosophy of technology develop after the Cultural Revolution? What did you and your colleagues contribute to post-Cultural Revolution developments?

YDY: As indicated, philosophy of technology in China began with philosophical research about technology during the Cultural Revolution, focused on issues related to certain individual technologies. Essentially this work had the character of case studies. After the Cultural Revolution efforts were made to consider technology more generally, as an independent subject matter—although not so much from an external, already established philosophical perspective, as happened in the West. This kind of research was initially called "theory of technology" [Japanese 技術の理論 *gijutsu no riron*/Chinese 技术理论 *jishu lilun*], a term adopted from Japanese philosophers, as the closest we could come to a name for what we were doing.

CM: May I interrupt here with a question? I am surprised that Japanese work in the theory of technology would have been influential in China. After all, Japan had invaded and occupied Manchuria in 1931 and established a puppet government with the last emperor of the Qing Dynasty. Then China had fought a War against Japanese Aggression from 1937 to 1945, during which the Japanese had used chemical and biological weapons developed by the notorious Unit 731 in Harbin. After all this, were Chinese scholars still open to working with Japanese scholars?

YDY: Yes, I grew up during that period—and you have to realize that like most Chinese in northeastern China, I had to learn Japanese. Japanese was the language of instruction beginning in primary school. We were not even allowed to think of ourselves as Chinese.

The reason why we worked with Japanese scholars after the Reform and Opening [as initiated by Deng Xiaoping in 1978] can be attributed to two reasons: first, as I said before, for me and many other Chinese scholars from northeastern China, Japanese was the foreign language and scholarly tradition we knew best, so it was just natural for us to communicate with and be influenced by Japanese philosophers. Take me, for example. When I talked to Japanese scholars in Japanese, because of the similarity of Chinese and Japanese, even the similar context, our understanding of concepts is basically similar, the communication goes smoothly. But when I talk with English speakers, such as you, communication is difficult. With some concepts we have to clarify many times to achieve mutual understanding.

As a matter of fact, the Japanese imperialist aggression and enslavement of China are a military and political issue. Even today the current Japanese policymakers are still not penitent, which upsets a lot of Chinese. However, as for civil exchanges and academic communication, it is quite different. For instance, when I was in elementary school, on the one hand, we hated the Japanese training director very much, but on the other, we got along very well with Mr. Sato, who taught us Japanese. When he was conscripted into the army and had to leave us in 1945, he cried. After the diplomatic normalization of Sino-Japanese relations, he visited us and we had a reunion in our old school.

Second, we also saw the Japanese as more modernized than us and so worthy of some imitation. Beginning in 1979 researchers in Northeastern University in Shenyang started collecting philosophical articles from other countries, especially Japan, for translation and publication in a special section of 科学与哲学研究资料 [*Kexue yu zhexue yan jiuzi liao* Science and philosophy studies] magazine under the heading "Theory of Technology." During the early days of the Reform and Opening enthusiasm about science was all over China. In this context scholars, mostly in Beijing and Shanghai, introduced the sociology of science, which in turn stimulated research on the science of science [a research field originally developed independently by Polish sociologists Maria Ossowska (1896–1974) and Stanisław Ossowski (1897–1963) and by British Marxist molecular biologist J.D. Bernal (1907–1971)]. Science of science research was further endorsed by the National Science Committee, and came to incorporate theory of technology work.

It was during this time that my colleague Professor Chen Changshu's books on 科学与技术的区别 *Kexue yu jishu de qubie* [Differences between science and technology] and my own 关于技术本质属性的讨论 *Guan yu jishu ben zhishu xing de tao lun* [Some thoughts on the fundamental attributes of technology] were published in an academic forum 技术理论与政策 *Jishu lilun yu zhengce* [Theory and policy of technology] hosted by the Institute of the Science of Science. A book 科学技术论 *Kexue jishu lun* [On science and technology] was written by scholars at the Institute of the Science of Science and used as a textbook for university classes throughout China. I authored its chapter "On Technology", and Professor Chen Changshu authored its chapter "Science, Technology, and Society".

In 1985 a branch committee for research on technology known as the Committee on Technology was established in the Institute of Natural Dialectics. It called for the first national meeting dedicated to the theme of technology. And it is at this meeting that Professor Chen Changshu was elected as the chairman of the Committee. In 1988 the name of this group was changed to Committee on the Philosophy of Technology.

During this period there were three organizations promoting developments in Chinese philosophy of technology and sociology of technology: the Institute of Natural Dialectics, the Institute of the Science of Science, and the Chinese Society for the History of Science and Technology. Additionally, the central government proposed that economic development should rely on science and technology, and science and technology should dedicate themselves to economic development.

Government policy nevertheless caused controversy. Is it science or technology on which the economy should rely? And in what ways? Subsequently the central government proposed that basic research should be emphasized—and that the policy should be to strengthen the application of scientific and technological research. This meant, on the one hand, supporting scientific and technological research and, on the other, promoting the application of science and technology to productivity. This new policy further emphasized the development of technology itself, thus opening an independent space for the development of philosophy and sociology of technology.

Another element in the social background at this time was that the Ministry of Education made a dialectics of nature course mandatory for all university graduate students in science and engineering. This both disseminated natural dialectics study and produced more scholars in the field.

For a while after the Reform and Opening, there were discussions about what technology was. But rather than seeking an abstract definition, the focus was on such questions as "Is technology a direct product force?" or "What is the social value of technology?" There were no metaphysical discussions about the nature of technology like those that took place in the West. The reason related to social reality.

In 1985 Deng Xiaoping had proposed that science and technology should become a direct productive force. But after he retired from the Central Committee of the CPC in 1987, his "productivity theory" was subjected to criticism. Politics was often involved in discussions of science and technology. Relationships among science, technology, production, and the economy have been a recurring theme in Chinese philosophy of technology, and as a result there have been continuing analyses of such issues as technical transformations within technology, the nature of technological invention and innovation, and their social conditions and influences.

This was no doubt influenced by the utilitarianism inherent to Chinese culture. Among Western Marxists there is a long history of the social criticism of technology. Indeed, Karl Marx himself criticized technology to some extent. In ancient China, as well, one can find elements of the criticism of technology. (In your own writing somewhere you mention the criticism contained in the shadoof story from the *Zhuangzi*.) But in modern China especially people have taken a strongly pro-technology attitude, avoiding critical reflection. We seem to have inherited from Marxism only a practical materialism. This is partly just the result of our economic reality and the need for economic growth and development.

CM: In the West it has become common to talk about various "turns" in the philosophy of technology: an "empirical turn," an "ethical turn," a "policy turn," etc. I wonder if you could describe similar "turns" as having taken place in China.

YDY: As I understand it, the alleged "empirical turn" in philosophy of technology in the West is associated with ideas about the social shaping of technology and the program from the 1980s for analyzing the social construction of technology. Social constructionists attempt to "open the black box" of engineering and technology by doing individual case studies, using primarily sociological methods. They openly criticize previous philosophy of technology, especially the metaphysical speculative philosophy of technology of someone such as Heidegger. Western philosophers of technology, especially those you associate with the classic humanities philosophy of technology tradition [see Carl Mitcham, *Thinking through Technology: The Path from Engineering to Philosophy* (Chicago: University of Chicago Press, 1993)], did seem to lack interest in real-world technology. What they offered was abstract philosophical reflections on technology as a whole. Thus opening the black box and making the empirical turn was quite necessary.

However, there are two issues here: First, is technology completely constructed by society? Industrial technological systems of engineering (工程 *gong cheng*) are clearly socially constructed, because different industrial systems exist under different social conditions, which is why industrial systems are never exactly the same in all parts of the world; indeed, not even in the same country is it possible for all steel plants or iron works to be identical. Identical *gong cheng* (engineering projects) do not exist either. Engineering is the integration of technology, but it is hard to believe that the basic principles of technology are completely constructed by society. From my standpoint, the rules of technology exist in accordance with the laws of nature and make use of the laws of nature for human purposes. The purposes vary among people. But the laws of nature and cause-and-effect relationships are invariable; they are part of nature and not socially constructed. Social constructionists have a tendency to go from one extreme to the other. In practical research it is actually quite difficult to make clear distinctions between philosophy of technology and sociology of technology.

Second, there is the question of whether there needs to be an empirical turn in Chinese philosophy of technology. My answer is No. Chinese philosophy of technology began by analyzing individual technologies—as in the philosophical analysis of building block module machine tool construction, which already opened a black box. My own ideas of technology as process and technology form theory also open the black box.

Philosophers of technology seek agreement by means of two types of argument. One is by induction from experience, seeking knowledge by reflective analysis on practical experience. The other is by deduction and the experiential testing of hypotheses. Even necessary cause-and-effect relationships formulated as natural laws have to be tested in experience; logical deduction is insufficient. So my opinion is that there is no need for an empirical turn in Chinese philosophy of technology, because philosophy of technology in China originated in empirical work. In fact, there may be a sense that what Chinese philosophy of technology needs now is more theoretical work, and it could profit in this regard by learning from the West. But we should be careful and not go too far in this direction.

CM: Would you like to make any further comments on the current state of the philosophy of technology in China?

YDY: I have been retired for many years, and I barely participate in academic activities or read too much current literature, so I am not qualified to make a comment to the status quo of Chinese philosophy of technology. All I can do is to offer some personal views. First of all, let me say a few words about what seems to me its plight at present.

In the late 1990s there was a strong disagreement with regard to what constituted the core problem in the philosophy of technology: Epistemology or axiology? The question was asked especially among Chinese philosophers of science. When philosophers of science began to take notice of technology, they attempted to model philosophy of technology after the philosophy of science by analyzing technology as a kind of knowledge. On this model, epistemology was the core issue. Two professors from Sun Yat-sen University in Guangzhou, Zhang Huaxia and Zhang Zhilin, co-authored a paper on this theme: 从科学与技术的划界来看技术哲学的研究纲领 (*Cong kexue yu jishu de hua jie lai kan jishu zhexue de yan jiu gangling* Re-thinking the philosophy of technology program on the basis of differences between science and technology) [*Studies on Dialectics of Nature*, vol. 17, no. 2 (2001)]. In response, Professor Chen Changshu and I co-authored 也谈技术哲学的研究纲领—兼与张华夏、张志林教授商谈 (*Ye tan jishu zhexue de yan jiu gangling—jian ye zhang hua xia, zhang zhilin jiaoshou shangtan* Comments on the philosophy of technology research program: Discussion with Professors Zhang Huaxia and Zhang Zhilin) [*Studies on Dialectics of Nature*, vol. 17, no. 7 (2001)]. Unfortunately, this exchange of ideas did not continue because Professor Chen Changshu became ill, but our argument was that axiology, rather than epistemology, was the core issue in philosophy of technology.

Recently it has been proposed that a northern school and southern school should be distinguished in Chinese philosophy of technology. And that the northern school specializes in technological axiology, while the southern school mainly engages technological epistemology. From my point of view, neither the northern school nor the southern school is qualified to be a "school." I cannot agree that there is such a thing as "northeastern school," because there is not yet any clear academic research tradition among a group of researchers in northeastern China.

In the beginning of this millennium, there emerged another related field, that of philosophy of engineering, with strong support from the Chinese Academy of Engineering. The idea was that philosophy of engineering and philosophy of technology were different but related and could complement each other. The original reason we created 中国工程师 (*Zhong guo gong cheng shi or* Journal of Chinese Engineers) was to give engineers a platform in which they could speak for themselves and we could enter into a dialogue with them. In the philosophy of technology we used to have close contact with engineers and engineering, but paradoxically the rise of the philosophy of engineering tended to introduce some distance. Engineers have left the philosophy of technology to work in the philosophy of engineering. This is now a serious challenge for the philosophy of technology.

CM: This seems like an important point. Could you elaborate a little more on what you see as happening in the philosophy of engineering? For you, how should philosophy of engineering be related to philosophy of technology?

YDY: It used to be that technology and engineering were closely related and somewhat interchangeable terms. However, in Professor Li Bocong's 工程哲学导论 *Gong cheng zhexue yin lun* (Zhengzhou: Daxiang Press, 2002) *Introduction to Philosophy of Engineering*, he proposed a science-technology-engineering trinity, differentiating engineering from technology. In this framework, technology corresponds only to technological invention, although according to my technology form theory, technology can refer not only to technological invention but also to production processes and industrialization. Professor Li does not see production and industrial technology as part of engineering. In response I objected that "the tripartite distinction makes such a strong boundary between *jishu* (technology) and *gongcheng* (engineering) that it breaks their connection." Subsequently Professor Li modified his view so that "technological elements constitute the basis of engineering and non-technological elements constitute the boundary parameters."

With regard to the relationship between philosophy of technology and philosophy of engineering, you have presented the emergence of philosophy of engineering as one of four new elements in a fourth generation of the philosophy of technology, rather than as a new independent discipline. [I WILL ADD REFERENCE HERE.] But according to the trinitarian distinction between science, technology, and engineering, philosophy of engineering is a new discipline, what I have referred to as a "new-born baby." When *Gongcheng zhexue yin lun* (Zhengzhou: Daxiang Press, 2002) *Introduction to Philosophy of Engineering* and then *Philosophy of Engineering* (Beijing: Higher Education Press, 2007) were published, I called philosophy of engineering a new-born baby because all previous work in this area was a preparation for its birth. But in fact it seems to me that philosophy of engineering has not so much created its own research paradigm as adopted the paradigm of the philosophy of technology. The scholars currently doing research in the philosophy of engineering were originally trained in philosophy of technology. If this continues, philosophy of engineering will not become a wholly new discipline but just be an extension of the philosophy of technology.

There is another issue here as well. At the beginning of the twenty-first century, philosophy of engineering, at least as a term, emerged simultaneously in both China and the West. But the two academic, social, and economic contexts are so different that one must wonder about the coincidence. You have suggested the empirical turn as an influence in the West. But as I have argued, I do not think there has been or needs to be an empirical turn in Chinese philosophy of technology. If this is so, then we need to ask whether the two philosophies of engineering are really the same or how they might be related.

Now let me return to the challenges in China with regard to further development of the philosophy of technology. The most serious institutional challenge comes from Ministry of Education. The requirement for the teaching of natural dialectics at the graduate level has been progressively reduced from 60 to 40 h and is now only 15–20 h. This means that the number of professors and researchers working in this area will inevitably decline dramatically.

How to cope with those challenges is the question posted in front of contemporary philosophers of technology. Our generation is the pioneer of this area, what we did is to build a shabby room with simple tools. Nowadays when you take a look back at this shabby room, it has its own characteristics. First of all, it emphasized the research of practical technology, directed by the practical problems during development of science and technology in the Chinese context, embodying the utilitarian spirit of traditional culture. Secondly, it kept close relations with technical professionals in engineering or technology universities or shop floor engineering and technical personnel. Thirdly, it paid more attention to science and technology policy research, which made it easier to get government support. Back then, the development of science and technology was backward compared with Western countries, so how to promote the development of science and technology and how to transform them to a productive force became a common theme. Lastly, Chinese philosophers of technology were more optimistic about technology rather than pessimistic. All in all, focusing on the practice is its unique strength, while lacking of enough theoretical sublimation is its obvious weakness. How to absorb nutrition from Chinese traditional culture and establish a complete theoretical system of philosophy of technology with Chinese characteristic still has a long way to go.

CM: Can you make some suggestions for the future research of Chinese philosophy of technology?

In the face of such a challenge, any empirical or other type of turn that does not address a real social need is obviously not an option. In this context, my personal proposal is that philosophy of technology shift from thinking about the relationship between technology and production to the relationship between technology and waste. In the past, Chinese philosophy of technology has emphasized how technology stimulates and contributes to the production of useful goods and services, that is, how it enhances productivity and economic development. But in China today we are increasingly aware that technology also can enhance waste and pollution. When the purpose of production is to consume, it naturally produces waste. In other words, not only the positive value of technology should be a theme of philosophy of technology, but the negative value should as well. It is the negative value that jeopardizes human life.

How should we think philosophically about waste? Until now, this has not been a question asked in Chinese philosophy of technology. But this is a question that needs to become a major theme of philosophical reflection in relation to technology. I would thus propose that philosophy of technology undertake the analysis of a fourfold relationship: 生产 (*sheng chan* or production), 生废 (*sheng fei* or waste), 生活 (*sheng huo* or livelihood), and 生命 (*sheng ming* or life). It is by appreciating correctly this fourfold relationship that material civilization construction and ecological civilization construction can be coordinated.

In this sense I think our current economics is just half of economics, because all economists today care about is what they should produce, how much they produce, by what kind of means, for whom, and who makes the decisions. Producing here only refers to useful products, rather than useless products. Similarly, our philosophy of technology is just half of the philosophy of technology.

CM: You began by thanking me for facilitating the publication of an English language review of your and Professor Chen Changshu's work. Let conclude by me sincerely thanking you for this discussion, in which you have helped me understand much better the historic-philosophical origins of the philosophy of technology in China. It is a fascinating story. But allow me also to add a small footnote to that history.

As you know, Professor Yin Dengxiang visited the United States in academic year 1990–1991 and did research on science, technology, and society (STS) studies with Professor Stephen Cutcliffe (who directed the Lehigh University STS Program) and with me (as director of the Pennsylvania State University STS Program). After Professor Yin returned to China, he brought Cutcliffe and me to China, where in June 1992 we did a series of lectures on STS at the Graduate University of the Chinese Academy of Sciences in Beijing. It was there that I actually had an opportunity to meet Professor Chen Changshu—indeed, he even hosted a banquet for Cutcliffe and me—although I did not in any way appreciate who he really was and the importance of his work. It is only now, many years later, that you have helped me appreciate this important scholar. For this I am deeply grateful to you.

After my 1992 visit I even had a small correspondence with Professor Chen Changshu. In 1996, during a visit to his daughter at the University of Virginia, he wrote to me at Pennsylvania State University saying he would like to arrange for the translation of my *Thinking through Technology* into Chinese. Because I was serving as a visiting professor at the Colorado School of Mines when his letter arrived, I did not respond until the following year. I observed that *Thinking through Technology*, because of its extensive references to technical engineering literature, might be difficult to translate, and suggested instead another book on which I was working at the time: *High-Tech Ethics: Learning To Live with Advancing Technology.* He responded with enthusiasm:

> It is a pleasure to receive your letter…. After discussion, my PhD students and I are very interested in translating your new book … into Chinese…. So if you think it is suitable for us to do what we are planning, please send me your new book….

I sincerely regret that I never completed that book project, and thus never sent it to Professor Chen Changshu for translation. I do not think I even ever explained to him what had happened. And yet a decade later (in 2008), I am sure as a result at least in part of Professor Chen Changshu's initiative, *Thinking through Technology* did appear in Chinese. So through you I would now like to apologize and to give my sincere thanks to him also, since you were one of his closest collaborators, and to some degree continue his spirit—and again to you, for all of what you and your colleagues have contributed to helping philosophers East and West continue to think through technology.

Supplementary Note: Since this interview was conducted, Chen Changshu's *An Introduction to Philosophy of Technology* has been published in English translation (Beijing: Science Press, 2016). The translation was done by Chen Fan, Ma Ming, and Howard Giskin.

Chapter 25
Humanities Perspectives on Science, Technology, and Engineering in China

LIU Dachun 刘大椿, Carl MITCHAM, and ZHAO Junhai 赵俊海

Abstract Educated initially in mathematics and science, Liu Dachun describes the important role books and literature played in his life and how they comforted him during the Cultural Revolution. Turning to his arrival at Renmin University of China during the Reform and Opening, he reviews contributions to the promotion of academic standards and development of the study of the dialectics of nature into the philosophy of science and technology. His own research focus during these years was on science as activity, complementary methodology, and the scientific-technological revolution. Many areas manifested tensions between adopting international scholarly norms and maintaining Chinese traditions. A lengthy concluding discussion considers relationships between science, technology, engineering, and industry, leading into an analysis of science policy challenges in China.

25.1 Introduction

The following interview is constructed from discussions that began in March 2015 at Renmin University of China and continued in various forms through June 2016. An initial stimulus was the intellectual autobiography that opens Professor Liu Dachun's 科学之审度: 刘大椿自选集 *Kexue zhi shen duo* [Reconsiderations of science: Collected papers] (Beijing: Capital Normal University Press, 2015), which collects papers across 30 years on

- Philosophy of science,
- Philosophy of technology,

In discussion with Carl MITCHAM and ZHAO Junhai 赵俊海.

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- Methodology,
- Science, technology, and society (STS),
- The reform of philosophy in China,
- The humanities and social sciences in China.

The discussion also draws on Liu Dachun’s presentation for a workshop on “Humanities Reflections on Technology and STPP (Science, Technology, and Public Policy) Studies” at Renmin University, June 29 to July 1, 2015, and Liu Dachun et al. 一般科学哲学史 *Yiban kexue zhexue shi* [A history of general philosophy of science] (Beijing: Central Compilation and Translation Press, 2016). In all cases, the exchanges between Liu Dachun and Carl Mitcham were made possible by graduate student Zhao Junhai, who worked not only as translator, but in close collaboration with both interlocutors.

25.2 Interview

Carl Mitcham: Professor Liu, you are now the leading professor in the philosophy of science and technology at Renmin University of China, which has the largest School of Philosophy in China. This School of Philosophy may also have the largest department for the Philosophy of Science and Technology in the world. Certainly it is one of a very few philosophy departments that takes technology as an explicit theme for critical reflection. But it has not always been this way, and your intellectual life can provide a background for understanding some of the important changes that have taken place in Chinese philosophical discourse related to technology over the last half century.

I note, for instance, that the first section of your intellectual autobiography carries the title “Making Friends with Books in Miserable Times” and that the personal inscription in the copy of this book that you gave me is “To learn is the best life” (a sentiment I share). Both of these remarks allude to a tradition in Chinese philosophy that can be traced back to the opening of Kongzi’s *Analects*: “Is it not pleasant to learn with continuing persistence and application? Is it not pleasurable to have friends coming from distant places?” So perhaps we could begin with some personal history on your own philosophical formation in this distinctively Chinese tradition.

Liu Dachun: Thank you for these questions and the opportunity to share some of my views on philosophy and the philosophy of technology with English speaking readers.

I was born in 1944 into an intellectual family and my father was a university teacher. In his generation, wars and political movements caused great suffering and bitterness. But when I was a teenager, I was nurtured very well by him, immersing myself with pleasure in books.

I entered secondary school in 1956 in No. 5 High School of Nanchang, which was known as the best in Jiangxi Province, and it had a library. I worked there as a volunteer, in order to have more access to books, to experience true happiness in the company of books.

The school was divided between the liberal arts and the sciences. What I studied was science, so that mathematics, physics, and chemistry took most of my time and energy. Meanwhile, I took personal pleasure in reading works of literature, history, politics, and philosophy. Since this was in the early years of the People's Republic, I read a good deal by Russian authors such as Alexander Pushkin, Fyodor Dostoevsky, and Leo Tolstoy—but also works by British authors such as William Shakespeare, Lord Byron, Charles Darwin, and Bertrand Russell; by French authors such as René Descartes, Jean-Jacques Rousseau, Victor Hugo, and Roland Romain; and by German authors such as Immanuel Kant, Wolfgang Goethe, G.W.F. Hegel, and Heinrich Heine. Additionally, I was fond of critical works by Nikolai Chernyshevsky, Vissarion Belinsky, and Nikolay Dobrolyubov. To develop my own critical sense, I had a habit of taking notes while reading, half excerpts and half reflections.

My childhood was full of hopes and dreams, and I had a wonderful time in high school. But contrary to my expectations, I received a low score on the college entrance examination; this was because of a tainted family background. I was only allowed to enroll at Jiangxi Normal College, which in 1983 was renamed Jiangxi Normal University. My fairy-tale world came to an end.

At the same time, I was lucky to have an opportunity to go to any university at all, even if not my ideal one. I studied at Jiangxi Normal College from 1961 to 1965. Jiangxi Normal grew out of National Chung Cheng University (established in 1940) and National Nanchang University (renamed in 1949), both of which were once well known. When I arrived, however, the college had been in decline for a while, although it still retained some eminent teachers and good traditions.

CM: Could you say more about your life at Jiangxi Normal College during this particularly difficult time in China in the early 1960s?

LDC: My college life was really meaningful. I studied science and read literature on my own. My major was mathematics, and I had 4 years of strict practice in mathematical reasoning, which has been important for the rest of my life. But I was a student with wide interests, rather than being narrowly focused, and hence I spent almost all my spare time reading all kinds of books. It was fortunate that the teachers did not criticize or dislike me because of wide reading. Since I worked hard, I digested what I learned in class more quickly than many others. Decades later, some teachers could still remember me.

I did not know how the Jiangxi Normal library compared with others in the province, but for me it was truly a treasure. Soon after entering the university, I walked around in the library with surprise and excitement. I thought I had read many books, but realized I had only begun to scratch the surface. Not only had I not previously been able to read many classical works, I had never even heard of important works in history, philosophy, politics, economics, and social science. I realized it would be hard but rewarding to read all the good books in just this library. Therefore, I made a private plan to select the most significant books and read them on a schedule. Every ten days I would return with a pile of books I had read and check out a new pile. It did not take long for librarians to notice me. At that time, we called the librarians "teachers", but to me they were more like friends.

Even though only nodding to each other when we met, there were two women librarians to whom I felt especially close. The older one was Teacher Luo, who was in her 30s but quite wise; she and her husband both worked in the library. The younger one was Teacher Tu, an elegant young woman whose husband taught Russian. Both librarians were always helpful in locating books for me. With their help, I read many of John Gunther's "inside" books: *Inside Europe* (1936), *Inside Asia* (1939), *Inside U.S.A.* (1947), *Inside Africa* (1955), and so on. Other books that began to give me a sense of the world outside China were Sidney Hook's *Marx in Limbo* (translated from *Towards the Understanding of Karl Marx*, 1933), John Strachey's *Contemporary Capitalism* (1956), Milovan Djilas's *The New Class* (1957), William L. Shirer's *The Rise and Fall of the Third Reich* (1960). When requesting a book I would just write down its title and one of the librarians would find it for me, even if it was not officially approved, sometimes also adding related books. Thanks to them I spent my 4-year university life sailing on this sea of books.

Zhao Junhai: And what was your life like after graduating from Jiangxi Normal College?

LDC: After graduation, I returned to No. 5 High School of Nanchang as a mathematics teacher. Just when I had adjusted to this new job, the Cultural Revolution began in May 1966. I was eventually sent to Jiugaowan Production Team in Duchang County near Poyang Lake. Initially I worked with peasants "repairing the earth", and then was promoted to a People's Community Propaganda Team to help make big character posters. Later I became a rural middle school teacher. It was 5 years before I was able to return to an urban area.

During that difficult time the only thing that comforted me was reading. Reading opens windows to the world, builds bridges to a higher spirit. Having books accompany you, you will not be lonely. Reading makes us get closer to other parts of the world and enlightens our lives.

CM: Were there any positive aspects to your experiences during the Cultural Revolution?

LDC: During the Cultural Revolution, I moved from living in an academic to a grassroots community, from an urban area to the countryside, from a relatively comfortable way of life to one of extreme poverty, all of which was hard for me physically as well as mentally. But this change forced me to think, and made me understand how difficult the lives of peasants were.

I was first sent to Jiugaowan, a district beside Poyang Lake with blood flukes, which made the lives of peasants there even harsher. I was not sent with a group but directly into peasants' homes to live with them. So I could see exactly how they lived, thought, what they did and wished for in life. My ideas changed a great deal during that period. In the past I had been too idealistic. Like one of the characters in Chernyshevsky's *What Is to Be Done?* (1863), I had been consumed by personal relationships and social contradictions, struggling with trying to figure out what to do and why. But in the countryside things were totally different. The need to work was ever present. Peasants had to work almost all the time. During the time of "double rush" (rush to plant, rush to harvest), they would get up early at 2:00 a.m. But by the end of year, when calculating your contribution to the production team, one day of hard labor was worth only a dozen *fen*. I was evaluated as worth only 70 % of the normal peasant laborer. It was embarrassing that strong peasants could do so much more work, although I tried my best and became exhausted every day. So since pay was proportional, I earned less than 10 *fen* per day. But as an educated youth who had been sent down to the countryside, I was paid an extra 50 *yuan* a month, while at that time peasants could not earn 50 *yuan* in a year.

Through that experience, I received what Russell calls "knowledge by acquaintance" in the way of life of the Chinese people, especially the peasants. I was forced to ask myself, Why do they have to work so hard and earn so little? What is to be done about this situation? What should we do in the face of these great hardships among our people? Afterward, when I arrived at Renmin (People's) University, I could not stop thinking about these issues. Although philosophy needs to reach upward to the spiritual level, it must have its feet on the ground as well. To study isolated from the people's needs is hollow.

CM: How was it that you moved from working in the countryside to Renmin University?

LDC: During the Cultural Revolution many universities were closed and the regular entrance examination process suspended. Then when the Reform and Opening began in the late 1970s the entrance examination for postgraduate students was restored, and people like me were given a new opportunity to take the exam. Initially I did not want to take the exam. I was then in my 30s and doubtful that there was much chance of succeeding, since from the 1950s my family had been stigmatized politically. It seemed like taking the exam might just be asking for trouble.

By then I had undergone the turmoil of the Cultural Revolution. I had lived and done farm work with peasants, worked as a barefoot teacher in rural primary and secondary schools, and had finally been given a teaching position in a teacher training college. Perhaps I should just be grateful to be a full time math teacher. So during the first year of the new examinations, I did not participate.

But in the second year, some teachers in our Jiujiang Normal College decided to register for the exam. These were teachers whose educations at universities such as Peking, Tsinghua, and Fudan had been interrupted by the Cultural Revolution. They wanted to return to university again and suggested that I join them in taking the exam. One of my best friends argued that family background was no longer so important. My father also encouraged me. If I did not try, he said, I would never know how things might change.

Then a question arose about which major to choose. One obvious choice was mathematics. But I knew that in math, people who did not make significant contributions before 30 would seldom achieve much later. What other options were there? I did not want something so general as the humanities, so I thought that the philosophy of science, which at that time was called "dialectics of nature", would be a reasonable alternative. I had some foundation in math and science and had read books on politics, history, philosophy, literature, and economics. The second issue was where to apply. A friend suggested Renmin University, so I made this my goal.

There was little time to prepare, since the examination took place only 1 month later, but I did well. The exam itself asked us to choose one subject from math, physics, biology, or astronomy; of course, I picked math. In only half the exam period I answered all the math questions and was confident of the results. In the time remaining I decided to look at the questions in physics, biology, and astronomy, and found that I could answer many of them. With inspiration, I answered one question in each of these other areas and wrote a few sentences saying that given time, I thought I could answer most of the others. The result was that I was admitted to Renmin University—which changed my life.

It is hard to say whether or not 1978 was the most important year in contemporary Chinese history. But in most areas, public or private, directly related to me, this year was an irreplaceable and conclusive transition.

ZJH: What was it like when you arrived at Renmin University in October 1978, after the university had been deconstructed and closed for 12 years (1966–1978)?

LDC: Let me share my memories of the first gathering of new students at the reopening of Renmin University of China. There was a special opening ceremony for us 108 new postgraduate students, but much of the campus was still occupied by the Second Artillery Force of the Peoples' Liberation Army (since December 31, 2015, renamed the PLA Rocket Force). Only Red Building One and several smaller buildings were available for university use. Everything was waiting to be rebuilt. But the primitive material conditions did not bother us at all. We had been through the Cultural Revolution, were in high spirits, and jokingly referring to ourselves as the "108 heroes" (with allusions to the 水浒传 *Shuihu zhuan* [*Water Margin*, one of the four great classic novels of China]).

In the afternoon, all postgraduate students, carrying folding stools, went into one small classroom full of enthusiasm. In a little while staff from the president's office called some of us near the door to go out and welcome our leaders. We found a gracious old Renmin President Cheng Fangwu walking vigorously toward us, not looking at all like his 80 years. Then another man, who had some difficulties with his legs, stepped out of a car and was immediately given two walking sticks. We knew this was Renmin President Guo Yingqiu. At that time, we called both Cheng Fangwu and Guo Yingqiu the presidents.

It was surprising to see them both standing in front of us. President Guo asked where we came from, how we had gotten here, and said that although the conditions were primitive now, they would get better. We responded that we were not afraid of hardship and it was our honor to be able to study here. President Cheng said happily that we were the hope of Renmin University and the nation.

When the presidents finished talking with us, the staff from the president's office took some photos of us with the two respected presidents against the background of several large campus trees. The photographs of that day bring vividly back to me that turning point in my life.

CM: And what about your studies and future life at Renmin University—or Renda, as it is commonly called?

LDC: In 1981 I earned a master degree in philosophy [until 1981, the MA was a terminal graduate degree in China] and then remained to teach philosophy. Even though dialectics of nature—a Chinese term that includes philosophy of science and technology—still belonged to humanities, it had a close relationship with engineering and technology. In 1983, realizing that Renda had few options for studying science and technology, I considered where we might start to add some disciplines in science and engineering. I wrote a letter to Renmin University Vice President Xie Tao in this regard. There was no immediate response and I gradually forgot the issue.

Then in late 1983 Professor Luo Guojie [Luo Guojie, 1928–2015, was a pioneering philosopher in the field of Marxist ethics and the vice president of Renmin Univerisy] was to be named dean of the School of Philosophy and he would need two assistant deans. Given my lack of seniority, I was quite surprised when asked to serve as one of the assistant deans. Later I learned that Vice President Xie had spoken in favor of me because of my letter. So my letter to Vice President Xie influenced my appointment as assistant dean.

In China at that time it was rare for a scholar in his 30s or 40s to be appointed to an important academic or administrative position. It was thus quite unexpected when, still in my 30s, I was given such a position. But Luo Guojie accepted me graciously and it is now a tradition at Renda to select people on the basis of merit rather than personal relationships.

I served as Assistant Dean in philosophy for 13 years, working first with Professor Luo Guojie and then Professor Chen Xianda [Chen Xianda, b. 1930, is a Marxist philosopher and current director of the academic committee of Renmin University]. Then in 1996 I was appointed Dean of the School of Philosophy. Four years later I was named Executive Vice President of the Graduate School. In that capacity I served on a number of national commissions. For example, I was successively a member of the fourth and fifth Philosophy Discipline Appraisal Group of the State Council and a Vice Director of the Philosophy Teaching Advisory Committee of the Ministry of Education.

In these positions I did my best to promote discipline construction in philosophy and the philosophy of science and technology. Even though such work is, in my view, important to realize oneself, my real interest remains in scholarship. Thus even though administrative affairs took up much of my time and energy, I did not allow them to completely displace my academic studies.

CM: Yes, and I understand that your academic research has also had an important influence in China. In this regard, could you say more about how you understand the philosophy of science and technology?

LDC: In contemporary China, philosophy of science and technology is regarded as is a kind of philosophical study of science and technology themselves and of science, technology and society (STS) relationships. Philosophy of science and philosophy of technology are its bases, and the history of scientific and technological thought, along with sociology of science and technology, are key elements. In short, philosophy of science and technology is a comprehensive discipline involving comprehensive philosophical reflection on science and technology.

My primary research interest is the philosophy of science and technology. My academic research in this area has proposed and emphasized three issues: science as activity, complementary methodology, and the contemporary scientific and technological revolution (or what in the West is sometimes called the rise of technoscience).

With all three issues, my generation has had to start from scratch. After a 10-year interruption in our academic lives, we were not able immediately to be international leaders in the relevant academic fields. In this respect we are a transitional generation, with one important contribution being to clarify issues.

Thinking first about science, when I started my teaching career, the question "What is science?" had an established answer. Chinese textbooks and dictionaries all defined science as systematic knowledge, and initially I accepted such a definition. However, as a scholar who had come from Jiujiang, a small city on Yangtze River, to Beijing, the capital of China, and from mathematics to philosophy, I began to study dialectics of nature, and was early on attracted to the ideas of John Desmond Bernal. [An Irish-born physicist and Marxist, Bernal (1901–1971) argued for understanding the social function of science. His book, *The Social Function of Science*, was translated into Chinese as 科学的社会功能 *Kexue de shehui gongneng* (Beijing: Commercial Press, 1982)]. For Bernal, science is not just systematic knowledge but also a human activity. This means that any epistemological analysis of science needs to be connected to discussions in psychology and sociology. This more comprehensive view of science excited me and fit with the implicit research approach in the dialectics of nature program. I subsequently developed this approach in 科学活动论 *Kexue huodong lun* [Science as activity] (Beijing: People's Publishing House, 1985). This book was received quite positively and helped provide Chinese scholars with a broader approach to the philosophy of science and technology.

For example, Gao Fang [b. 1927, a professor of Renmin University of China and a well-known Chinese scholar of Marxism, socialism, and the history of the Communist Party of China] agreed with my argument, but pointed out that my approach left out the social sciences. I therefore undertook to study social science as an activity, and this research was promoted in the social science project of the national 7th Five-year Plan [1986–1990]. In 1992 this effort led to my book 走向自为:社会科学的活动与方法 *Zou xiang ziwei: shehui kexue de huodong yu fangfa* [Orienting toward being-for-itself: The activities and methods of the social sciences] (Chongqing: Chongqing Publishing Group). The argument here adopted the terminology of Hegel and proposed that the social sciences be seen as special human activities, which contribute to a process of society moving from being-in-itself to being-for-itself.

Thinking about science as activity naturally led to critical reflections on methodology. Methodology should not be seen as simply directions for scientific knowledge production. Methodology needs to be understood in broader and more interdisciplinary ways, in both theoretical and practical terms. My thoughts on methodology were primarily expressed in 比较方法论 *Bijiao fangfa lun* [Comparative methodology] (Beijing: China Institute of Culture, 1987). This early publication was later revised as 互补方法论 *Hubu fangfa lun* [Complementary methodology] (Beijing: World Affairs Press, 1994).

My argument was that scientific methods, like science as activity, are historically conditioned. The proper attitude is not to rigidify scientific methodology at some stage of development but selectively to learn from various methods. Any method works in a specific context and has its ranges and limitations. Different methods can complement rather than compete with each other. If our thinking is expansive enough, we can adopt numerous methods and use them all in a cooperative manner. Complementary methodology can be regarded as a kind of methodology from multi-perspectives.

CM: I cannot help but add that your ideas here on complementary methodology are closely related to work on the methods of interdisciplinarity that were being independently developed in the United States during this same period. One good early statement of American research in this area is Julie Thompson Klein's *Interdisciplinarity: History, Theory, and Practice* (1990). I wonder if you know this work.

LDC: I do not know this work. But certainly I have for some time been aware of the notion of interdisciplinarity and it indeed could be another way to approach my argument concerning complementary methodology from multi-perspectives.

CM: I wish I had known of your work on complementary methodology when I was working with Klein and Robert Frodeman to co-edit the *Oxford Handbook of Interdisciplinarity* (2010). This handbook clearly should have included some reference to your work.

LDC: Your compliment is appreciated. Let's look for future opportunities to discuss this more.

Turing to the contemporary scientific and technological revolution, I began work on this issue near the conclusion of my research on complementary methodology. My thinking about the contemporary scientific and technological revolution or technoscience was influenced by Deng Xiaoping's affirmation in the late 1970s and early 1980s of "science and technology as primary productive forces." Recall that Deng himself promoted the reopening of Renmin University as an important step in the Reform and Opening process. It was Deng who stimulated policies to promote science and technology for economic and social development. Under the historical circumstances of the 1980s, the interactions of science and technology, politics, economy, and culture began to attract scholarly research not only in China but in other parts of the world as well. In this regard I authored or coauthored a number of articles and several books on the technoscientific revolution related to the sociology of scientific knowledge, such as 中国科技体制的转型之路 *Zhongguo keji tizhi de zhuanxing zhi lu* [China's transition of the scientific and technological system] (Jinan: Shandong Science and Technology Press, 1995); 科技生产力:理论和运作 *Keji shengchanli: lilun he yunzuo* [Productivity of science and technology: Theory and operation] (Chongqing: Chongqing Publishing Group, 1996); 现代科技导论 *Xiandai keji daolun* [Introduction to modern science and technology] (Beijing: Renmin University of China Press, 1998 and 2009); and so on.

ZJH: Could we return to the issue of the relationship between the dialectics of nature and the philosophy of science and technology? Many foreign scholars have trouble understanding what Chinese philosophers mean by dialectics of nature.

LDC: Dialectics of nature is a special academic field with ideological characteristics. Initially, its goal was to analyze science and technology using Marxist theory. Because of its close relations with philosophy of science and technology, it gradually became a specific branch of philosophy. In short, what in China during the 1980s was called the dialectics of nature—adapting the term from a book by Frederich Engels (*Dialectics of Nature*, first translated into Chinese in 1932), which argued for seeing dialectical relationships in nature as well as society, and thus implied the need to examine relationships between science, technology, and society—involves the same general topics as the philosophy of science and technology understood broadly. In fact, suggesting the importance of Engels's book is the fact that there are at least five Chinese translations of it published in 1932, 1950, 1955, 1971, and 1984. In China the related topics have ranged from "science and technology as primary productive forces" and "the transformation of Chinese scientific and technological culture" to "scientific and technological ethics" and "the development and assessment of innovation in Chinese humanities and social science." But it is the shift among these topics and the general move from the term "dialectics of nature" to the "philosophy of science and technology" that most interests me.

In the late 1970s, in reaction to the denigration of technical expertise during the Cultural Revolution, education in science and technology, including education in the philosophy of science, were widely promoted. Political reforms rectifying the mistakes of the Cultural Revolution along with scientific and technological education aimed to "bring order out of chaos." In this context, the dialectics of nature, which at the time was primarily general philosophy of science, because of its universal, classless, and transnational character as well as its close relationship with science, seemed to fit in with what was taking place in the Reform and Opening, and unexpectedly began to play a leading role in ideological emancipation. Dialectics of nature became part of the renaissance in universal, classless, transnational philosophy in China. The 1980s thus witnessed a large-scale introduction of Western theories into the Chinese academic world. Although this had some benefits and laid a foundation for further studies, there was also a tendency to be satisfied with superficial knowledge and follow foreign things.

During this period, a number of universities started teaching dialectics of nature courses. A standardized educational program with Chinese characteristics for postgraduate and PhD students in this major was established in some universities, which cultivated many high-level experts and formed a specialized sub-discipline in philosophy: philosophy of science and technology (dialectics of nature). Academic disciplines as well as leading frontier questions, such as the ethical issues of science and technology, public policies of science and technology, were discussed more deeply than before. This revival of teaching and research in the dialectics of nature occurred at a particularly appropriate time.

Insofar as dialectics of nature became an academic specialization, it had not only ideological significance but was manifested in scholarly research. Through reflection on theory and practice, I summarized an emerging consensus among academic colleagues about the dialectics of nature and how it should be taught (Liu Dachun. "基本点不动摇, 功能有特色, 学科要拓展" *Jibendian bu dongyao, gongneng you tese, xueke yao tuozhan* [Never shaken basic points, functions accompanied by characteristics, disciplines to be expanded], *Studies in Dialectics of Nature*, 1993, Supplement 1). First, the basic point should never be shaken. The basic point is that science and technology are a bridge to Marxism. Second, dialects of nature education should function to help students build a scientific world view by informing student thinking with the latest scientific and technological knowledge. Third, the discipline, including its guiding ideas and updated teaching materials, must be expanded.

Academically, during the 1980s and 1990s Renmin University played a key role in promoting research in the philosophy of science and technology (dialectics of nature). During this period, I was fortunately in an influential position, so that I and my colleagues were able to establish some standards for this discourse.

Dialectics of nature was once profound and had lots of Chinese characteristics, in that it emphasized not only scientific but also political perspectives, including the influence of social and political factors as well as academic ones. When I first worked in Renmin University from 1981 to 1987, I preferred to study philosophy of science and technology on my own. I wanted to absorb all kinds of approaches, including those originating in the Soviet Union as well as Europe and America, while maintaining the Chinese characteristics of the dialectics of nature.

In 1987, there was a modification of the disciplinary catalogue, a national education document originally created in 1983 by the State Council Academic Degree Committee and Ministry of Education to authorize degrees, set disciplines, and supervise disciplinary development. At that time, Professor Xiao Qian and others (including Professor Luo Guojie and part-time Professor Chen Changshu) in the Renmin University School of Philosophy were the primary leaders in this modification. As the subdean in the school at that time, I had certain rights to speak about it. So I talked with Professor Xiao Qian about development of the dialectics of nature and proposed two points: First, that we needed to improve its academic level and not to be slaves to political power; second, that we do our best to adapt dialectics of nature to the international norms in the philosophy of science and technology. He agreed and put forward his own suggestions. Eventually the Ministry of Education accepted our recommendation to change the name of "dialectics of nature" to "philosophy of science and technology (dialectics of nature)". The parenthesis was added to placate those who were afraid of weakening Marxism and therefore had raised several understandable concerns. Later on, most people got used to this new name. No matter what we called the discipline, the important thing was how we studied and what we included. But the term "dialectics of nature" was foreign to scholars in Europe and the United States, while "philosophy of science and technology" was quite clear.

Once the name of the discipline had been decided, then came basic teaching materials. Renmin University played an important role in editing them. I edited some of the core materials still in use today in a common required course, such as 自然辩证法概论 *Ziran bianzhengfa gailun* [Introduction to dialectics of nature] (Beijing: Renmin University Press, 2004 and 2008). My textbooks for a professional course — 科学技术哲学导论 *Kexue jishu zhexue daolun* [Introduction to philosophy of science and technology] (Beijing: Renmin University Press, 2000 and 2005) and科学技术哲学概论 *Kexue jishu zhexue gailun* [Philosophy of science and technology] (Beijing: Renmin University of China Press, 2011)—continue to be regularly reprinted. Additionally, my 科学哲学 *Kexue zhexue* [Philosophy of science] (Beijing: People's Publishing House, 1998; Beijing: Renmin University of China Press, 2006 and 2011) is recommended as necessary reading by many universities.

In summary, from the 1980s on, Renmin University of China has been the leader in developing the discipline of the philosophy of science and technology (dialectics of nature): that is, on determining its name, teaching model, and main materials. We have also organized the Chinese Society of Dialectics of Nature (from 2006 to 2012, I was nominal vice president, and since 2012 vice president) as well as the Beijing Society of Dialectics of Nature (with Professor Wang Hongsheng as president from 2007 to 2015).

CM: This all provides very useful background for Western scholars, and perhaps for some younger Chinese scholars as well. Could you also say something about philosophy education in China more generally?

LDC: Philosophy has become a prominent subject in contemporary China. The philosophy study campaign in the 1950s and the 1960s made philosophical terms and concepts buzz words that are known to every Chinese person. During the ideological liberation movement in the 1980s people again paid attention to philosophy. However, since the 1990s, though great progress has been made in academic and professional education standards in philosophy, philosophy has become much less popular as a major; popular education in philosophy has been reduced to a mere formality and outward show. This decline may be partially attributed to changes in an increasingly fickle social atmosphere, but it also exposes many weaknesses in contemporary China's rigid philosophy education. This is an issue of great concern.

Most obviously, the problem arises from overlooking research in the philosophy of education. Education depends largely on methodology, to which educators in all countries, from Confucius to Comenius, from Socrates to Kant, have paid attention. However, education in China has for several decades been directed by the government, without attending to work in the philosophy education. This neglect keeps philosophy teachers from creatively integrating contemporary philosophical ideas and best educational methodologies in their practice; they are bogged down in illusions.

As Karl Jaspers once said, education is an extremely serious business. Education gives birth to new generations of life, work, and communication. From the cultural and spiritual perspectives, the goal of education is to maintain the sustainable evolution of human civilization. It is the process whereby a new subjective spirit of social individuals is constructed by a common human objective spirit, and from this inheritance there is hope to continue to recreate the objective spirit. Given this, people can easily see the important function of educational activities. But if we emphasize only the means as an end in itself, we will slight the real goal of education, which is to achieve the sustainable development of civilization, and we will fail to see that to deepen knowledge and understanding among students is the only right path to achieve our goal.

According to my observation and research, the real difference between deliberate indoctrination and education in improving the quality of students is that the former shows a dogmatic attitude in treating the objective mind, trying to use techniques of indoctrination in education, and training those being educated simply to conform to existing social modules; while the latter is based on the objective spirit and individual subjective spiritual interaction, to cultivate and comprehend the essence of objective spirit, to help students meet real life challenges, and to enable them to become new members of an evolving society.

Specifically, I have written about how indoctrination instead of deepening understanding actually undermines true philosophical reflection. Years of such practices in the philosophy department have been converted into several articles and brought about some modest changes, but the results are not impressive.

ZJH: Could you say something about how you understand the differences and relationships among science, technology, engineering, and industry? Is there any need for philosophy of engineering to separate from the philosophy of technology, especially in China?

LDC: First, science, technology, engineering, and industry are four distinct activities: science focuses on discovery, technology on invention, engineering on construction, and industry (which is based on market benefit) on scale production.

Second, science, technology, engineering, and industry, though distinct, are closely related. Scientific knowledge can be used to transform nature into artifact through productive means. But the natural laws discovered in scientific theory and the creative ideas involved in invention are not direct productive powers. Turning the combination of theory and creative ideas into productive activity requires technological means, productive skills, and engineering design. Only based on financial investment, raw materials and resources, along with organized processes and control, can we set up large-scale production activities that transform the world.

However, science, technology, engineering, and industry exhibit many special relationships under different systems and cultures. For example, the historical development of the Industrial Revolution in England in the 1800s related science, technology, engineering, and industry in quite different ways than that in China today. In England individualistic industrial capitalism played a more prominent role than is the case in twenty-first century China, where the state experiences more direct influence. Furthermore, although technology and engineering have generally developed together, they have not always been in balance.

As a kind of creative activity, engineering aims to improve the conditions of human existence. This activity is progressive in applying scientific knowledge and technological means through organized human activity to transform the natural world into an artificial one in ways that are more valuable for humans. What is primary in this process is engineering and the engineer. The great achievement of engineering is material production and material utility.

A necessary step in the development of the philosophy of technology will thus be the development of the philosophy of engineering. This is based not only on the fact that engineering is central to social production and the material foundation of human existence, but also because there are some philosophical issues unique to engineering itself, and engineers are themselves concerned with philosophical issues. Additionally, since engineering activity is another form of human subjectivity, for philosophy to ignore engineering would be to ignore human subjectivity. Such elements are the basis for the emergence of the philosophy of engineering. The emergence of philosophy of engineering and its separation from philosophy of technology is an inevitable stage in the development of science and technology and an urgent social development, especially in the context of China's modernization.

Philosophy is the intellectual quintessence of its time, so that in our historical period of engineering, the philosophy of engineering will express the philosopher's serious reflection on the modern human engineered world and way of life. The development of the philosophy of engineering is altering the contemporary map of philosophy.

CM: What are the impacts of science, technology, and engineering on society and humanities? How are we to reflect on science, technology, and engineering from the perspectives of the humanities?

LDC: Since science gained its special social position as a result of the Scientific Revolution and the Industrial Revolution, it gradually developed into a close connection with industry and commerce and strengthened its manipulating power throughout society. At the same time, after overthrowing the political dominance of churches and religions, based on its wide and profound social influences, science became allied with political power and hence developed into a kind of ideology and cultural belief. We can say that science and the technology driven by science has integrated into a trinity consisting of power, production, and faith. Science developed into a kind of authoritative discourse and ideology and became a dominant factor in the political, economic, and cultural areas.

But the dominance of scientific culture provoked extreme antipathy from other elements of culture. Many non-scientific cultures, especially the humanities, began to criticize science. The cultural dominance of science enabled it to gain honors that other elements of culture never had, and yet the distance between science and culture as a whole only increased. Scientism arrogantly rejected the humanities and any integration with a larger culture, and hence became a kind of cultural danger. Thus it becomes necessary for the humanities perspective, especially the ethical perspective, to reaffirm its important cultural role.

In late 1990s, I became strongly interested in the ethics of science and technology. The main research result was 在真与善之间——科技时代的伦理问题与道德抉择 *Zai zhen yu shan zhijian: keji shidai de lunli wenti yu daode jueze* [Between truth and goodness: Ethical issues and moral choices in the era of science and technology] (Beijing: China Social Sciences Press, 2000). Modern science and technology are not only material practices; they also constitute pioneering experiments in social ethics. Through the development of modern science and technology the practice of human communication is becoming increasingly complex, and at the same time, human activities have increasingly prominent, far-reaching consequences. As a result, people are forced to abandon the idea that technology is neutral and any blind optimism about technological progress, and to accept the burden of great responsibility for increasingly amazing science and technology. The negative effects of science and technology make people aware not only that ethics should be an internal dimension of science and technology, but that it is progress made by science and technology that rapidly expands ethics to new areas and in new directions.

ZJH: Indeed, recently you turned toward ethics and policy issues. Can you say something about this development?

CM: Yes, I likewise am interested in your recent turn to policy issues related to science, technology, and engineering. This is a shift that has also taken place in the philosophy of technology and STS studies in the West. From the perspective of philosophy and the humanities, what do you see as the most important issues in science policy?

LDC: In China there are four basic issues related to the promotion and proper utilization of science, technology, and engineering: the problematics of a state-run system, academic freedom, relationships between knowledge and power, and science and technology as both private and public goods. Let me say a word about each.

The Chinese state-run system to promote science, technology, and engineering research and development is different than the system in the United States. It is perhaps closer in structure to the systems in some European countries such as France.

Advantages of the Chinese system are that it can provide superior resources—economic, social, political, and academic. It makes scientific careers and what Derek de Solla Price called "big science" central to the national economy. Difficulties arise in deciding exactly what types of science, technology, and engineering to support, and what criteria to use in making these choices. The "Matthew effect" (of sociologist Robert Merton) of providing more resources to those who already have them is a challenge. In a state-run system, the important thing is to balance governmental control and market mechanisms, and adequate opportunities for small science projects must be protected.

The need to protect the development of small projects relates to the second issue, academic freedom. On the one hand, academic freedom is important in order to nurture a spirit of independence and research that is not influenced by extraneous factors. On the other, scientific research should not just remain in an ivory tower wholly divorced from society.

There are at least three factors that can distort the practice of academic freedom. One is the idea that all research must be politically endorsed. Another is political control of universities. Still a third is excessive pursuit of practical results and national prestige. In China there is sometimes too much emphasis on projects that are "short, safe, and fast". The quest for Nobel Prizes in science can also be a distorting factor. In China there is a perennial problem of properly coordinating political power and academic freedom. A "politics first" principle is a persistent challenge.

For China to address these factors it will be necessary to establish a teaching and research management system that can mediate political power and academic freedom. To this end, it will be important legally to clarify the academic status, responsibilities, and rights of research institutions. Scientists and engineers must be allowed to function as the real makers of research goals and operational mechanisms. This is a particularly important issue for China.

A third issue is again related, that of the collusion between knowledge and power. From Plato’s *Republic* to contemporary ideas about technocracy, there has been an emphasis on power being properly exercised by those with knowledge. Michel Foucault has also argued that knowledge and power are inherently connected and that science is regularly institutionalized as power.

When collusions between power and knowledge create inequities, the state must undertake micro and macro measures to establish a healthier social environment. For this purpose, genuine dialogue between intellectuals and the public should be promoted in ways that increase public participation in policy and scientific decision making. Scientists themselves have responsibilities for helping to do this, for communicating with the public and educating non-scientists about the purpose, effects, and even operational processes of science. In turn, the public has obligations to properly supervise scientific activities.

But in all this we should be vigilant about the separation of knowledge and power. Science involves knowledge production in search of truth, universality, and through individual creativity. Power demands compromise and obedience. Knowledge production is decentralized, whereas power promotes centralization. When knowledge tries to attach itself to power, it runs the danger of losing its independence. When power tries to increase itself through taking control of knowledge, it can undermine the very thing from which it seeks to benefit.

Finally, there is the issue of science and engineering as both private and public goods. Science and engineering—especially in the form of big science and big engineering projects—aim for utility. Innovation is supposed to produce new private and public goods. What policies are appropriate for managing science and engineering to promote both private and public benefits for society?

The state should at once acknowledge and support basic scientific research and protect the intellectual property of technological inventors and engineers. But today Chinese research is facing serious challenges to the independence of academic disciplines. These challenges come from both the private and public spheres. Corporations want to control scholars and so do government officials. These efforts at control are directed not only toward science and engineering but toward the humanities and the social sciences as well. In both cases we must work to preserve appropriate levels of independence and integrity in science, engineering, the humanities, and the social sciences.

Afterword: Some Missing Elements

Paul T. DURBIN

The East-West approach of this volume, featuring mostly Chinese and American contributions, does a good job supplementing those contexts with contributions from countries other than just China and the USA. There is no reason to quibble with the contents of any specific contributions. Yet there are two general weaknesses that deserve to be noted.

First, there seems to me inadequate acknowledgment of prior work that I and others have contributed to developing the philosophy of engineering in the West. For instance, although there is one passing mention of an early edited volume on *Critical Perspectives on Nonacademic Science and Engineering* (Bethlehem, PA: Lehigh University Press, 1991), two important issues that figure prominently there are largely absent in the present collection. *Critical Perspectives* was produced at the request of Steven Goldman of Lehigh University Press, who originally invited me to edit a book simply on the philosophy of engineering. I broadened the focus to include those with whom so many engineers work in what is called "Research and Development" in industry and government. A discussion of the close interactions between engineers and scientists deserves attention in any philosophy of engineering.

Additionally, *Critical Perspectives* opened with an essay on engineering method, as manifested especially in engineering design, by Billy Vaughn Koen. Indeed, I would credit engineer Koen and philosopher Goldman with giving rise to the philosophy of engineering field, such as it exists in the West. Koen then went on to generalize his analysis in an outstanding book that places engineering within the overall tradition of innovative thinking—not only in engineering but in philosophy

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as well. But discussions of engineering design, method, and Koen himself receive only limited mention in this collection.

A second general weakness concerns the issue of engineering itself. The editors credit Taft Broome with pointing out that the biannual meetings of the international Society for Philosophy and Technology (SPT) have included too few contributions by engineers themselves. The effort to remedy this weakness led to creation of the Forum on Philosophy, Engineering, and Technology (fPET), whose 2012 meeting stimulated creation of the present collection. But even a casual perusal of the perspective on engineering associated with the American or Chinese Academy of Engineering reveals a spectrum of activities much broader than represented here.

The web site of the U.S. Academy of Engineering, for instance, currently emphasizes a series of "Grand Challenges for the 21st Century." These challenges complement an earlier national academy summary of the grand contributions of engineers to the history of the twentieth century. What is immediately apparent with regard to both past and future is how much of engineering that *Philosophy of Engineering, East and West* leaves out. Only one of the four editors is an engineer, and only about one quarter of the contributions are by engineers, with the primary references to engineering being mostly limited to civil and mechanical. There is little to no mention of chemical engineering and its offshoots in biochemical, biomedical, and genetic engineering; of electrical and electronic engineering; of aeronautical engineering or space engineering; of nuclear or nano-engineering. In short, many readers—and not just engineers—are likely to feel that this volume leaves out more than it includes in the way of engineering.

Despite these weaknesses, however, *Philosophy of Engineering, East and West* should help advance discussion in this emergent field. It will be a welcome addition to the interaction between philosophy and engineering.

Index

Note: While focused on proper names, the index also aims to provide a sense of the conceptual scope of the volume. What is not indexed: text in the front matter and Introduction that references contributors or details of book organization. Only when Chinese names have been westernized is a comma placed between family and given names. Figures are denoted with *f*. (The index was prepared by Judy Gordon.)

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