# Enlarging Intersections between Engineering and Ethics: Thoughts on Engineering Ethics Education

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Abstract—Ethical dimension inherently exists in engineering, separating ethics from engineering is the root-cause of many engineering accidents and conflictions. A qualified engineer must have ethical consciousness and abilities in ethical decision making and behavior. Engineering ethics education has been proved to be a feasible way to achieve this goal, and it is of high necessities and urgencies according to Chinese current situation. However, domestic engineering ethics education development is much slower than the western developed countries. Based on the background of "National Excellent Engineer Training Scheme", this article reviews the development history and status quo of engineering ethics education, puts forward some major reform elements and the related countermeasures for Chinese engineering ethics education.

*Index Terms*—Engineering education, engineering ethics, ethics education, qualified engineer

### I. INTRODUCTION

At present, there are 1047 undergraduate colleges set up engineering majors, accounted for 91.5% of the total number of undergraduate colleges; almost 4,523,000 students' majors are engineering, accounted for 32% of the total number of undergraduate college students. The scale of technical talents cultivation of China ranks first in the world. In order to improve the quality of technical talents training and serve the construction of innovative country better, Chinese Education Ministry has launched and implemented the "Excellent Engineers Training Scheme" in some leading universities and listed it into the outline of the national medium-and long-term program for education development. By the end of 2010, 194 undergraduate colleges and universities have joined in the "Excellent Engineers Training Scheme".

It is a long-term and systematic engineering for implementing the "Excellent Engineers Training Scheme". It is important for engineers to amass technical knowledge, but it is more important for them to have a sense of social responsibility and moral consciousness to shoulder the mission of sustainable development of human society. Therefore, to strengthen the engineering ethics education for engineering major students has become the urgent task to every university. Take the "Excellent Engineers Training Mingfeng Jiang Research Institute of Science of Science and Management of Science and Technology Dalian University of Technology Dalian, P.R.China jiangmf sky@sina.com

Scheme" as an opportunity; it is imperative to reform the engineering ethics education.

Valuing engineering ethics education is a common trend internationally. After experienced the negative effects and disadvantages brought by rapid economic development, many western countries emphasize considering overall impacts of various types of engineering activities on human social life, ethical issues and education have attracted increasingly attention. Compared with western developed countries, Chinese engineering ethics education development is relatively slow; this is the most important reason of some phenomenon such as cutting corners and "tofu dreg construction". So it is urgently needed to connect the "professional excellence" with "ethical integrity" to establish an integrated education system for cultivating future engineers through engineering ethics education. This paper discusses the necessities and urgencies of engineering ethics education, analyzes its history and status quo, and puts forward some major reform elements and the related countermeasures of engineering ethics education.

### II. THE NECESSITIES, URGENCIES AND FEASIBLITIES OF ENGINEERING ETHICS EDUCATION

### *A. The notable affair that makes engineering ethics raise public concern*

In 1970s, there were two notable affairs that engineering ethics aroused public concern, one of them is the Ford Pinto fuel tank event. At that time, the Ford Motor Company has produced 12,500,000 Pinto including 11,000,000 cars and 1,500,000 small trucks. If each vehicle was reinstalled the fuel tank, it might avoid 180 deaths, 180 extensive empyrosis and 2,100 vehicle burning accidents. If the compensation for one death accident, one extensive empyrosis, and one car burning accident was 200,000 dollars, 67,000 dollars, and 700 dollars respectively, then total compensation for all accidents would be 49.5 million dollars. But reinstalling the fuel tank of each vehicle would cost 11 dollars, for all vehicles it would cost 137 million dollars. Contrast these two different situations, the benefits of reinstalling fuel tanks is far less than the cost. Hence the engineers of Ford Motor Company chose not to reinstall the fuel tank. As one can imagine, it caused huge casualties, the reason of the accidents is that the scientists and engineers who engaged in the R&D activities are interested only in profits, while pursuing that consumers' benefits and public safety were ignored.

### B. Ethical dimension is the inherent character of engineering

In fact, ethical responsibility and technicality constitute the inherent attributes of engineering together. Bunge said, "technology can be either a blessing or a curse" [1]. Dean of American Academy of Engineering Wulf, has particularly pointed out that the great majority of the social impacts of engineering has not been foreseen by the inventors when reviewing the major engineering achievements in 20th century. He thinks that over the past 100 years, engineers and their engineering have created profound impacts on our lives more than any other people and work, they impacted both positively and negatively, sometimes unexpectedly, widely, and irreversibly [2]. American scholar Martin and others found that in a product's whole life cycle, from design to manufacturing, sale, until discarding as useless, each process contains ethical problems [3]. Therefore in order to make sure that the engineers insist on the moral principles when using technology, popularizing and promoting engineering ethics education in colleges and universities is very necessary. A survey found by McGinn shows, more than 90% of the engineers think that college students should experience a variety of ethical issues during their formal engineering education because they will encounter these issues in their future careers. 53% to 70% of the engineers point out that either they themselves or their colleagues have encountered ethical problems during the engineering practice, and they hope to have been better prepared so as to deal with those issues effectively [4].

### *C. Technologial advances increase the importance and urgencies of engineering ethics education*

Goldstain has pointed out in his famous book Die Technik, As technology advances, there will be completely new, nonrational (or anti-rational) situations, namely, improving technology and improving human moral standards can not keep in the same pace[5]. Since human beings came into 21st century, with ever increasing rate of technological innovation, modern engineering has more and more social impacts. Frequent engineering accidents, energy crisis and environmental pollution make the engineering ethical issues unprecedentedly serious and complex. In this situation, engineers as the main body of engineering activities, their ethical decision-making ability is especially vital; hence it is important to strengthen the engineering ethics education. American bridge engineering scientist David P. Billington has noted [6], ethics is not an additional or separate area for engineering courses, it should be an inherent part of engineering and ethical dimension should be the core of engineering education reform. Nowadays fostering talents equipped with consciousness of professional ethics and social responsibilities has increasingly become one of the internal goals of university teaching, engineering ethics education is the

foundation to strengthen engineering education in colleges and universities.

### D. Feasibilities of engineering ethics education

Can engineering ethics be taught to the students? Though it is still controversial, some scholars have provided evidence that one's moral quality can be improved to some extent by proper ethical training, especially for young adults. Bishop put forward a convincing proof for this hypothesis: "A person's value system is not static or immutable; it is more likely to be significantly corrected with the change of time, particularly in early life" [7]. An empirical study on moral psychology has also proved that through the complex social interactions with colleagues and other important figures, one's ethical development can continue until at least young adulthood (20 to 30 years old) [8]. Piper brought strong evidence to prove that moral development could enter the adult world, especially in the context of a professional school education, where young adults might be changed dramatically by drawing on empirical research results of others, combined with Development via Constructive Learning theory, and his research carried out at Harvard Business School [9]. Of course, ethical quality of an adult may develop under a variety of formal and informal situations, but now there is ample evidence only by at least formal education can one's ethical awareness and responsibility continued to be transformed. Whether ethics can be taught to adults or not, the key point is to define the educational goals. Hence we can make sure if the goal of education is to help students to analyze the ethical difficulties of the situation, or to provide theoretical, module, or methods may be useful in dealing with ethical dilemmas, or make them more sensitive to certain kinds of behavior which may implies misconduct in ethics, or to provide an alarm for their later professional career through case studies, ethics can be educated.

### III. INTERNATIONAL AND DOMESTIC DEVELOPMENT OF ENGINEERING ETHICS EDUCATION

Engineering education develops along with its research. The United States is the most representative country of engineering ethics research and education. Its history can be divided into three major phases: the first phase is before 1900 when there was neither cross between research on engineering and ethics nor ethical considerations in engineering. The second phase is from the beginning of 20th century to 1970s when continuous enlarging of engineering scope and scale caused many contradictions between engineering, nature and society, and therefore ethical issues were highlighted increasingly, attracted more and more attention of public and authorities concerned. Since the 1970s, it has came into the third phase of so called institutionalizing period of engineering ethics, when engineers began to be requested to make judgments both on economic and technical value of the engineering project and its ethical value.

Since the 1980s, the U.S. Accreditation Board for Engineering and Technology (ABET) which is responsible for engineering accreditation commission, clearly demanded that any certified engineering education plan must include ethics

education content. In 1990s, American Association for Engineering Education (ASEE) and National Research Council (NRC) respectively delivered critical reports on engineering education reform, which addressed the ethical issues of engineers, and appealed for appropriate educational countermeasures. Since 1996, engineering foundation examination for registered engineer qualification in the USA has included ethical content. Since the 21st century, American engineering ethics education has entered a new stage. Recently, ABET's 52000 Engineering Standard 6 (Engineering Criteria 2000) requires (see ABET. 2000. http://www.abet.org) that engineering graduates must show their understanding of the professional and ethical responsibility, and have accepted a broad education to understand the influence of engineering project in global and social context, as well as have knowledge of contemporary issues. In the United States, it is visible that engineering ethics education not only plays an important role in engineering education, but also has its guaranteed system.

Over the course of nearly a half century, engineering ethics education in colleges and universities of the United States has obtained considerable development. Other countries such as Germany, Canada and Japanese have also established relatively mature engineering ethics education system. In 1989, the United States, Canada, New Zealand, Ireland, England and Australia signed an international agreement called "Washington Accord" to make it clear the basic goals and requirements of engineering ethics education, followed with South Africa, China Hong Kong, Korea, Russia, Singapore, etc, more than a dozen countries and regions have become the interim State Party Organization, China succeeded in joining this organization in 2013.

Among these contracting countries and regions, with its unique oriental cultural background, Japan has provided a global example for application of engineering ethic s education experiences of the U.S. How to establish a suitable education mode of engineering ethics to meet the needs of social development and reaches international level is an urgent affair. According to the result of our investigation on more 3000 undergraduates in 10 engineering colleges and universities in northeast China, although a little quantity of engineering ethics courses have been offered, the engineering undergraduates still lack consciousness of engineering ethics, so do some teaching staff. For most of the engineering colleges and universities, there is no uniform syllabus and teaching norm, mainly simple and dated teaching content and methods, theory and practice are disconnected, ethics education mode is still in exploratory stage (see table 1).

### TABLE 1. ENGINEERING UNDERGRADUATES' CONSCIOUSNESS OF ENGINEERING ETHICS

Points of	totally		relatively		noutral		relatively		totally	
view	disagree		not agree		neutral		agree		agree	
	frenqu	percent	frenqu	percent	frenqu	percent	frenqu	percent	frenqu	percent
Ethical	ency	age	ency	age	ency	age	ency	age	ency	age
elements										
should be	-		212	10.4	205	12.2	1165	20.0	1050	25.0
considered in	/8	2.6	312	10.4	395	13.2	1165	38.8	1050	35.0
engineering										
decision										
Engineering										
should put										
economic	275	9.2	1025	34.2	549	18.3	630	21.0	521	17.4
benefits in										
ne jirsi place										
Meeting										
sustainable										
development criteria										
should be	90	3.0	450	15.0	570	19.0	1095	36.5	795	26.5
No.1 success										
standard of engineering										
projects										
Honesty is										
No.1	36	1.2	230	7.7	424	14.1	1100	36.7	1210	40.3
engineers										
Engineers			C							
should be										
loyal to the society and										
his country	20	0.7	110	3.7	250	8.3	520	17.4	2100	70.0
more than										
nis own organization										
Data										
falsification										
should be prohibited	100	3 3	370	123	450	15.0	570	19.0	1510	50.3
no matter	100	5.5	570	12.5	-50	15.0	570	17.0	1510	50.5
what										
situation Engineering										
undergradu										
ates should										
be taught	20	1 2	72	2.5	200	67	200	12.0	2200	76 7
now to aeut with	50	1.5	12	2.5	200	0.7	390	15.0	2300	70.7
engineering										
ethical										
Engineering										
ethics										
courses are	450	15.0	960	32.0	540	18.0	600	20.0	350	117
regularly in	F-50	15.0	,00	52.0	540	10.0	000	20.0	550	11./
my										
university Engineeri										
ethics test										
should be										
applied in	20	1.0	120	10	240	<b>0</b>	780	26.0	1820	61.0
examination	50	1.0	120	4.0	∠40	0.0	100	20.0	1030	01.0
of all kinds										
of certified										
engineers	1									

### IV. CONTERMEASURES SUGGESTED FOR EGINNEERING ETHICS EDUCATION REFORM

## *A. Proper positioning of goals and content of engineering ethics education*

There were 4 points of expected targets, summerrized by M. Davids, an American engineering ethicist, when he taught engineering ethics: Improving moral sensitivity, increasing

understanding of professional behavior norms, enhencing ethical judgment abilities, and strengthening ethical willpower [10]. This view has been generally accepted by American engineering ethics educational circles. Use it for reference, goals and content of domestic engineering ethics education reform should reflect the following aspects:

1) Improving students' moral sensitivity and ethical consciousness

According to our investigation, the first reaction of engineering undergraduate to ethics education might be: What's the relationship between ethics and engineering? What is the use to lean it? The reason hiding behind is the lack of moral sensitivity. American scholar Augustine found that when engineers get trapped into ethical dilemma, usually it results from unconsciousness towards ethical issues rather than bad personal moral characters, in other words, indifferent ethical consciousness is an important root-cause makes engineers' misconducts in dealing with engineering issues involving social and ethical factors, or even leads to serious illegal consequences [11]. The first aim of engineering ethics education is to change this situation of indifferent ethical consciousness of engineering major students. Let the students know a good engineer should not only focus on technical features and economic benefits of engineering projects, more attention should be paid to social and ecological effects of engineering projects to realize the unification of economic, social and ecological benefits.

### 2) Defining clear the overall social responsibility of engineering

Meeting the needs of human sustainable development depends on not only the engineer's pesonal behaviors, but also behaviors of the whole engineering. In fact, Engineering ethics can be divided into two parts: micro ethics of individual technology or technological practitioners and macro ethics of overall technological system; in other words, micro ethics of relationship between engineers and customers, colleagues and employers, and macro ethics of overall engineering responsibility. Traditional engineering ethics education focuses too much on engineers' individual ethics issues rather than overall problems. With progress of times and development of society, emphasis of engineering ethics is changing from micro to macro level. After World War II, social responsibility of the whole engineering is highlighted, public safety, health and welfare became the prior responsibility in engineering activities. So engineering ethics education should adapt to these changes, expand education content including discussing ethics meaning of public policy, and define clear social responsibility of whole engineering, especially emphasize on keeping dynamic balance of giving-and-taking relationship between human and nature.

### 3) Enabling students to master methods of ethical decision

In addition to primary obligation of public safety, health and welfare, engineers need to know the principles of handling relationship with employers, colleagues, workers, and clients. Many issues may be involved such as conflicts of interests, project quality and security, authenticity of data, loyalty, trade secrets, bribery, and engineering practice in the international environment, etc. Traditionally, codes of engineering ethics dealing with these relationships were taught highly in principle, lack of specific training of application in engineering practice. Engineers would face massive ethics issues which cannot be resolved by simple ethical intuition and insight, or a direct reference to engineering ethics principle; they require a complex and rational engineering ethics decision-making to resolve the so-called Ethical Dilemma. For example, conflicts between loyalty to employers and protection of customers and public interests are the common ethical dilemma that engineers may encounter. To help engineers in ethical decision-making, some methods have been developed and tested to be useful, such as line-drawing and creative middle way suggested by Harrris, an engineering ethics educator in the U.S. [12] and priority principle proposed by German technological philosopher Lenk. Engineering ethics education should provide students with methods of dealing with complex situations, and enhance their abilities of ethical judging and decision-making in addition to describing basic criteria of engineering ethics.

### *4) Illustrating engineering ethics combining with international situation*

Engineering ethics education should not only make future engineers understand basic requirements proposed by human sustainable development plan, and ethical codes of dealing with verious kinds of relationship, but also focus on engineering ethics issues in context of globalization. With the process of globalization, many multinational projects are transferred from a certain culture to a totally different one. This transfer demands externalizing some inherent ethics and responsibility implied in engineering activities of one country, so that the ethical issues in a cmplex international engineering project could be clearly recognized, implemented and monitored by external personnel involed. Without specialized engineering ethics research and education, this task cannot be fulfilled.

### B. Adopting appropriate course mode and teaching methods

Engineering ethics are generally taught in two different modes. Firstly, compulsory course mode. A separate engineering ethics class is offered for compulsory credit hour, which allows teachers and students to discuss ethical issues within concentrated time and provides students with skill training and in-depth knowledge directly. This course mode can attract experienced teachers to involve in teaching, and improve other teachers' interests in teaching engineering ethics. Its disadvantage lies in seperateing engineering ethics from other courses, students who learn this subject may potentially take engineering ethics as a soft course and look down on it. Secondly, interdisciplinary course mode, which means intergrating engineering ethics education to various engineering courses, i.e., take courses of science and technology and society (STS) as a whole [13]. This pattern are gaining more and more applications recently. It integrates thought of engineering ethics to technology course with practicality and non burden added in any new course, makes students know ethical issues while they are underclassman. Help them fully understand social background of engineering, importance of engineering ethics, and improve engineering

students' interests in making ethical decisions as a part of project. However, this pattern scatters ethics education in each course, which may affects educational depth and continuity, its teaching efficiency is not easily to be tested and evaluated. Thus these two modes both have advantages and disadvantages, and they should be chosen appropriately combined with the specific feature and curriculum system of each college and university.

After teaching aims and tasks have been defined, method becomes a key priority. With regard to teaching methods of engineering ethics education, we highly advocate case teaching which was initiated by the Harvard Business School and has become the most common method of American engineering ethics education. National Science Foundation (NSF) of the U.S. has funded two case studies related with engineering ethics in 1992: introducing ethics case studies into compulsory course, and instructing case teaching method of engineering ethics. Case teaching selects typical engineering ethics cases associated closely with engineering practice, encourages students to establish ethical consciousness, identify ethics issues, express ethical opinions, and emphasizes the interaction between teachers and students, equal discussion, even debateing, and finally reaches consensus. Not only would it can appeal to students, but also has realistic guidance for their later work.

Major difficulties in case teaching could arise from less previous researches and cases accumulation on engineering ethics in China. To overcome these difficulties, on the one hand, we should discover and arrange domestic cases (such as decision-making process of Three Gorges Project); On the other hand, resource of existing foreign cases could be taken as a mirror. Ethics Review Committee, a subsidiary of National Society of Professional Engineers (NSPE) of the U.S., has accumulated abundant of cases for decades. Harris et al. listed 70 categories cases in the book *Engineering Ethics: Concepts and Case.* Certainly, those cases followed with the code established by NSPE. How can they be applied in specific situations of China? We should absorb selectively according to Chinese situation.

In addition, Internet is also an important teaching method of engineering ethics. Foreign countries have provided us good references. e.g., Ethics Centre for Engineering and Science, Engineering Ethics Institute at Texas A&M University, and National Center for Professional and Research Ethics at University of Illinois, funded by NSF, provide teachers and students a lot of engineering ethics cases, syllabus, engineering ethics rules, relevant documents, papers, reports and news. National Academy of Engineering (NAE), NSPE, Institute of Electrical and Electronics Engineers (IEEE) also has set up websites for ethics study. Those practices are worthy of learning.

Finally, Ethics study could be integrated into practice session organically such as practical teaching and graduation thesis. Engineering ethics is both professional ethics and practical ethics. Students should be guided through methods of observing, perceiving, and reasoning, internalize engineering ethics into to their spirit, and form self-conscious awareness and actions. This is also a good and necessary method for engineering ethics education.

### C. Combining explicit and implicit education together

There are two major types of orientation in education methods of engineering ethics education. One is explicit education in main channel; the other is implicit education of infiltration mode. The former claims to unify engineering ethics education with syllabus, textbooks and compulsory or elective credit hours; The latter claims to penetrate engineering ethics education into all courses or activities that students may come into contact with, including campus culture, mass media, teachers' personality and so on, through which to make students immerse in and influenced subtly to enhance their cognitive capability of engineering ethics. The latter could make up for shortages of the former; therefore, we should further explore the carriers and approach of implicit education to make it complementary to explicit one.

### D. Establishing social supporting system

Society plays a strong role in influencing popularization and intensification of engineering ethics education. Primary measures, like enhancing ethical direction of public opinion, publicity, and exposure of violating morality, should be taken to cultivate cultural environment for advocating engineering ethics education. Through various of media, such as television, newspapers, Internet, etc., arouse public outrage for unethical engineering behaviour and impose pressure on engineering education reform ultimately. More important, research on engineering ethics should be encouraged to promote teaching. Besides, we need to set up a scientific evaluation index and system for engineering ethics education as soon as possible. Engineering education has made superior progress in evaluating engineering seniors' "hard" skills, but relatively fallen behind in evaluating their "soft" qualities such as professional ethics situation [11]. This is a common problem internationally, and deserves making further effort to solve.

### V. SUMMARY AND OUTLOOKS

The importance of engineering ethics education is becoming more and more prominent along with social development and science and technology progress. Only by grasping both the engineering technology teaching and the engineering ethics education, synthesizing them in a systematic way, can the training of excellent engineers be integrated and comprehensive. Yet improving students' engineering moral quality through engineering ethics education in colleges and universities couldn't accomplish in an action and it is a longterm and arduous work, because the whole education process is restricted by many factors from society, campus and the students themselves. There is no doubt that these restriction conditions will not only limit the popularization of engineering ethics education but also influence the education process and the effects. In order to improve the popularity and effects of engineering ethics education in our country, we need to find a suitable practical paradigm on the basis of learning from the theoretical and practical achievement of western developed countries, as well as deeply researching on national conditions.

At the same time, an all-inclusive guarantee system covering guidance, execution, supervision and evaluation should be established as soon as possible, among them many issues have not been recognized and need further study and exploration.

### ACHNOWLEDGMET

The authors thank for the financial support of undergraduate educational innovation project of Dalian University of Technology.

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