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Cultivating Critical Thinking and Mathematical Thinking in Relation to Civil Engineering Higher Education

Wang Ying[1, 2, *], Zhu Meichun[1]

[1]College of Civil Engineering, Shanghai Normal University, Shanghai, China
[2]School of Civil Engineering and Built Environment, Edinburgh Napier University, Edinburgh, UK

Email address

wycyt2000@163.com (Wang Ying)
[*]Corresponding author

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Abstract

The present phenomenon of knowledge explosion and technology advancement has a requirement for engineers with the ability to acquire and use new knowledge and skills critically. The symbiosis between mathematics and engineering is so well established that the fluency with mathematics is an essential weapon for the young engineers. After a brief overview of critical thinking (CT) and mathematical thinking (MT) in relation to civil engineering, the current scenario on teaching and learning of engineering education will be developed. Some viewpoints about academic curriculum and educators correspond to CT and MT in the field of civil engineering will be discussed.

1. Introduction

In today's globally connected and rapidly changing world, it can be seen that knowledge and technology are expanding exponentially. Problems and issues such as global warming, pollutions, constructions, environments, economic or political crisis are becoming more challenging, more complex and are increasingly threatening us [1]. Even though information is readily available from the internet, the challenge and difficulty to filter such information independently and usefully in making the right decision is a major drawback. Therefore, it is timely and crucial for the future generation to realize these unmet needs.

Undoubtedly, for the betterment of humankind, better solutions to most of the issues, challenges and changes should be offered. The inability of young graduates to compete and face challenges involving complex real-world engineering problems has been well documented. Consequently, it raised an issue that the engineering higher education should prepare the students with the required CT and MT knowledge, skills and values for such challenges. In this paper, the CT and MT skills are firstly reviewed, the relationship and interaction between the two skills in the engineering workplace are subsequently discussed, and lastly the teaching and learning approaches in relation to CT and MT skills in civil engineering higher education system are analysed.

2. Critical Thinking

There are many definitions on CT according to different perspectives. CT generally considered as ability to apply knowledge and intelligence in making decisions and giving opinions on issues [2]. That means, CT is a mode of thinking, it can improve the quality of thinking about any subjects, contents, or problems, by skilfully analysing, accessing and reconstructing thoughts. Making good judgement with desirable outcome is the product of thinking process, in agreement with having CT which use those cognitive skills or strategies in increasing the probability of a desirable outcome. Ability to think critically is very important in keeping abreast with the rapidly changing world.

Having mental agility and intelligence does not promise ones can think critically. Ability to think clearly and rationally indicates that someone is having CT. At the same time, the person also is able to engage in reflective and independent thinking. Someone with CT skill is able to understand the logical connections between ideas, able to identify, construct, analysis, and evaluate arguments, can detect inconsistencies and common mistakes in reasoning, ordering, solving problems systematically, do identify the relevance and importance of ideas, and also able to reflect on the justification of one's own beliefs and values.

In our developing country, a growing population is demanding well maintained infrastructures and creating demands for civil engineers to deal with all sorts of complex engineering problems. Civil engineers are facing many challenges including preparing new structures and maintaining aging infrastructures such as rebuilding bridges, buildings, tunnels, waste treatment plants, repairing roads and upgrading dams. According to the report of U.S. Department of Education (ERIC) [3], the jobs of science and engineering skills were growing almost five percent per year, while the rest of the job market was growing just over one percent. Although the figure reflects that this profession is in high demand, it means nothing if it does not come together with its quality. Civil engineers are always faced with challenging problems, and they are expected to solve these problems soundly, with higher quality solutions, therefore, ability to think critically to provide effective solutions is absolutely indispensable.

3. Mathematical Thinking

Mathematics, which has long been acknowledged, is an instrument of acquiring knowledge and as a tool for explaining, reasoning and analysing engineering systems and processes [4]. Normally, mathematics is regarded as a tool for cultivating thinking skills because mathematics learned in engineering higher education stage is not only going to be used for jobs but also to teach the skill how to think in mathematical way. Consequently, an approach to support MT and create a bridge to link mathematics to problem solving in engineering fields is indispensable.

As a lecturer teaching civil engineering courses to students, the author Wang experienced in observing different ways of approaching engineering mathematics learning among the undergraduate students. This experience has seen the lack of ability among students to apply and integrate mathematics knowledge into engineering subjects. Most of the students at their first two years in university treated mathematics only as an isolated subject, confined to its own boundary. When students were learning engineering courses involving area calculation, the students found it difficult to do calculations solving problems determining the area of an irregular polygon with curve sides. Because the students had learnt about differentiation and integration in mathematics, they were required to apply mathematics knowledge to solve the problem. After that, they tried to use more mathematics knowledge to solve engineering problems, the MT skill were cultivated step by step.

The American Society of Civil Engineering (ASCE) defines civil engineering as a profession in which a knowledge of mathematics and physical sciences gained by study, experience, and practice is applied together with judgment to develop ways to make materials and forces of nature for the benefit of humankind [5]. It can be seen that all areas of civil engineering rely on mathematics to gain quantitative analysis results of engineering structures. Therefore, mathematics has a vital role in civil engineering higher education.

4. Critical Thinking and Mathematical Thinking Used in Civil Engineering Practice

Unfortunately, information about CT and MT in engineering practice is found lacking in the previous literature. A preliminary study was executed by Osman etc. [6] though interviewing and observing on civil engineers at a civil engineering consultancy film. Osman etc. [7] studied the pertinent elements of CT and MT used in civil engineering practice in relation to engineering education though open coding practice in modified grounded theory analysis. Both the two articles uncover the relationship between these two thinking to provide better and deeper understanding on how both thinking are being applied in executing engineering tasks. Radzi etc. [8] discussed the connection between teaching and learning of engineering mathematics and math-oriented CT.

As generally acknowledged, familiar with mathematical expressions is essential for the study and application of any scientific, technical or engineering fields. To facilitate the engineering students' learning mathematics, it is not only to enhance students' ability to apply the mathematical knowledge and skills analytically, but also to think critically. Furthermore, many engineers will require frequent updating their specialization because they are facing the situation created by the ever rapidly pace of technological

development. This brings the necessity of mastering new techniques and understanding of new theoretical concepts. The symbiosis between mathematics and engineering has been proved very high in engineering practice. Any new advancements in civil engineering field are supported by new mathematical theories. Thus, fluency with mathematics is an essential weapon to the young civil engineers. Otherwise, they would be stay on one side only witness these knowledge and technological advancements. As future engineers in the field of civil engineering, it is really undeniable that someone should have the qualities of CT and MT skills.

5. Cultivating Critical Thinking and Mathematical Thinking in Engineering Education

5.1. The General Situations

According to BOK2 ASCE [5], the civil engineering students must be equipped with the ability to apply engineering basic principles and mathematical knowledge in analysing and solving complex engineering problems. By parallels with the similar situation in China [9], the program outcomes and student outcomes of a civil engineering curriculum are expected to know and be able to perform several attributes by the time of their graduation, such as: 1) An ability to search and filter the research literature refer to analysis complex engineering problems reaching reasonable conclusions based on the principles of mathematics, natural sciences and engineering sciences. 2) An ability to combine the knowledge of mathematics, science, engineering fundamentals with engineering specialisation to solve the complex engineering problems, 3) An ability to use the techniques, skills and modern engineering tools (such as engineering software) for engineering practice, and 4) A quality of global perspective (such as master a foreign language or/and use Euro-code) [10].

Take Shanghai Normal University (SHNU) as an example, it is a general phenomenon that the civil engineering students are with wide variety of educational background [11]. To match the program outcomes [9], the educators has performed a higher level of education program with relatively greater emphasis on applications and problem solving. This situation naturally generates distinctly different levels of capabilities among the students in the classroom. This results in urgent need and proper measures to balance the two extreme cases. One is to ensure the most able students are not deprived of sufficiently developing CT skills. At the same time to ensure that the less able students have rewarding and relevant CT competencies at the appropriate level.

The present situation of acquiring knowledge in civil engineering higher education appears to have a high tendency towards exam-oriented environment with more than 70% of the overall assessment being allocated for tests and examinations. This kind of assessment system seems to suggest knowledge acquired is in such a way to make it useful in the context of a structured exam. Actually, knowledge should be taught for use especially for engineering practice rather than for exams. Such teaching-learning current situation does not inculcate healthy development of CT among engineering students who on the contrary need to be prepared to face novel unexpected problems that call for sound critical reasoning.

5.2. The Way Forward

In view of above, the engineering curriculum should provide skills including critical, creative and MT along with science and engineering knowledge. There are some considerations as follows based on integration of CT and MT into teaching-learning environment.

Referring to the academic curriculum about programme structure and course contents, and balanced curriculum, the arrangement of engineering curriculum should suitable for all students with different educational background. The students should have ample opportunities for analytical, constructive, critical and creative thinking, and math-oriented decision making and rational thinking.

The engineering curriculum should also provide opportunities for skill training such as CT and MT skills, except the knowledge of mathematics, science and engineering for students. For example, mathematics study is not only to recite formulas but also to think mathematically and to use flexibly in engineering practice. It is strongly recommended that the future engineering curriculum should be built around developing skills and not around exam-oriented.

Mathematics is a potential medium to enhance the ability of engineering students for engaging in CT and MT skills through mathematical problem solving. Accordingly, there would be a challenge for the academics especially the engineering mathematics educators for they should be able to see the connection between the mathematics and the respective engineering field. Moreover, the university administrators and faculty members need more knowledge of what civil engineering does, how it does, and what the graduates need to know to function effectively in an engineering environment. Figure 1 is a schematic diagram illustrating the importance place of mathematics in the field of civil engineering in relation to skill training.

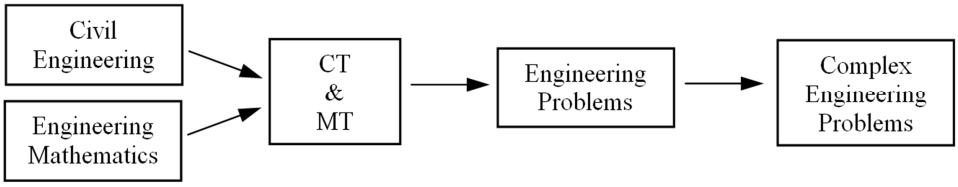

Figure 1. *Schematic Diagram showing the Role of Mathematics in the Field of Civil Engineering.*

6. Conclusion

In brief, this paper discussed in detail what the CT and MT was relation to the field of civil engineering. And the important role of CT and MT played in civil engineering practice was also analysed. In order to serve the technology-driven society of the present era, the engineering students should be imbued the math-oriented thinking skills based on the symbiosis between mathematics and civil engineering. In order to expose the shortcomings concerned with CT and MT skills of engineering higher educational system in China, the present teaching-learning educational system was briefly presented using SHNU as an example. This study lastly contributes some considerations to help the engineering educators to strength engineering instructions by arranging suitable curriculum and constant self-improvement.

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