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CURRENT AND FUTURE TEACHING OF ENGINEERING MATHEMATICS TO CIVIL ENGINEERING STUDENTS: ISSUES RELATING TO EMPOWERING AND ENHANCING CRITICAL AND CREATIVE THINKING SKILLS

Napisah Mohd Radzi
Shahrin Mohamad
Mohd Salleh Abu

The future engineering curriculum should be built around developing skills with much focus on shaping analytic skills, problem-solving skills, and design skills. Future engineers must be educated and prepared to be creative and flexible, to be curious and imaginative. Substantially, surveys and findings have also revealed that most employers and educational institutions recognize the importance of effective critical and creative thinking skills, especially among engineers. Despite the current demands, there have been some marked significant complaints relating to the capability among engineering graduates and young engineers to transfer methods and knowledge from one discipline to another. This ability forms an essential and necessary condition for pushing the boundaries of engineers' thinking. Mathematics being integral to engineering, is becoming ever more indispensable as the complexity of engineering tasks grows and abstract information processes start playing an essential role in technology. This is a strong indication that fluency with mathematics is an essential weapon in the modern graduate engineer's armory. Hence the teaching of mathematics to the engineering undergraduates too is never spared from the current requirements and demands. This paper seeks to explore and examine the current and future teaching of engineering mathematics to undergraduate civil engineering students at Universiti Teknologi Malaysia (UTM) pertaining to the empowerment and enhancement of critical and creative thinking skills.

10.1 OVERVIEW

The current global phenomena of knowledge explosion and technology advancement have impacted the engineering profession and engineering education. With the present environment, lies the challenge of what exactly and how to educate and prepare our engineering students for the future work force and how this might differ from what is taught today [1]. A prior initiative of the National Academy of Engineering reported that any attempts to prepare for the future of engineering may have to ask, "What will or should engineering be like in 2020?" [1]. In practice, it appears that it is the norm of engineering departments to develop curricula with preset problems or predicting the problems we expect to face. In doing so, we have focused on knowledge rather than developing skills. On the contrary, the emphasis should be on teaching to learn rather than providing more knowledge. As noted by the National Academy of Engineering [2], the future engineering curriculum should be built around developing skills and not around teaching available knowledge. Much emphasis should focus on shaping analytic skills, problem-solving skills, and design skills. It further stated the necessity to teach future engineers to think analytically, to be creative and flexible, to be curious and imaginative.

The importance of achieving effective critical and creative thinking skills among engineering graduates have been significantly emphasized by many world prominent engineering educators [3], [4], innovating organizations, such as research and development organizations [5], [6], [7] and also industry perspectives [8]. The Engineering Accreditation Council for the Board of Engineers of Malaysia place similar emphasis on the curriculum pertaining to analytical, critical, and creative thinking [9]. There is considerable evidence of employees' creative thinking skills making significant contribution to innovation in organizations [6], particularly in confronting with novel problems and uncertain situations [10] and where habitual or routine processes cannot be easily developed to find solutions to problems [11].

Despite the current demands, Sharon & Fischer [12] indicated some marked significant complaints relating to the limited capability among engineering graduates and young engineers to transfer methods and knowledge from one discipline to another; yet developing this capability is a necessary condition for pushing the boundaries of students' thinking. Additional highlights on marked decline in students' analytical powers are corroborated by other researches too [13], [14]. It is the experts' unanimous consensus to include analysis as a core skill to critical thinking [15]. Consequently, inadequacy in analytical abilities would inhibit the healthy growth of critical thinking.

The correlation and substantive integration of mathematics to engineering can be felt by the new framework set out by SARTOR 3 [14] which recognizes the skilled application of a distinctive body of knowledge based on mathematics alongside that of science, technology, business and management as an integral part of the formation of an engineer in the UK. The prime constituent of mathematics to engineers is again emphasized by SARTOR 3, when the degree accredited to chartered engineers amongst others will

- produce graduates with an understanding of mathematics as a method of communicating results, concepts and ideas

- produce graduates with the ability to use mathematics as a tool for solving complex problems
- produce graduates who can intelligently use and adapt mathematical models to represent real engineering problems

The Guidelines of the Joint Board of Moderators' reiterate that analytical treatment should be comparable in depth to the highest international standards, with “mathematics at a high level forming a significant part of the course” [14] whilst the London Mathematical Society et. al. [13] stated that mathematics is the only effective language for the analysis of problems and for the communication of results and ideas. Similarly, Maillardet [16] restated the imperative integration of mathematics in engineering with mathematics being the vital communication and modeling language.

As the complexity of engineering tasks grows and abstract information processes start playing an essential role in technology, mathematics is becoming ever more indispensable. The new wave of change which spawn new areas of focus in the various engineering disciplines would offer invaluable opportunities for engineering to develop new technologies to address the problems faced by society [1]. The symbiosis between engineering and mathematics is so well established that every new advancement in engineering would mean new ideas and theories in mathematics need to be explored.

However, surveys and findings carried out by the Society for Industrial and Applied Mathematics (SIAM) in the USA and by the MathSkills Project and the Institute of Mathematics and It’s Applications (IMA) in the UK, shows convincing evidence of the need to change the way in which undergraduate mathematics is taught and learned [17], [18]. Other researchers [19], [20], [21], [22] indicate sound evidence with similar themes of dimensions regarding serious problems associated with mathematics education for undergraduate engineering students. Aroshas et. al.,[23], McKenna and Smyth [24], on the other hand, suggest several teaching methods that may be helpful in assisting engineering undergraduates who encounter specific learning difficulties in the learning of engineering mathematics.

10.2 A QUICK LOOK AT THE ENGINEERING MATHEMATICS SUBJECT IN UTM

10.2.1 THE CURRENT SCENARIO

After the attainment of Sijil Pelajaran Malaysia (SPM) which is equivalent to the 'O' levels in the UK, qualified Malaysian students have to go through a matriculation period of one or two years depending on the achievement of their recent results in SPM. Another significant group of entrants attain Sijil Tinggi Pelajaran Malaysia (STPM) which is equivalent to 'A' level in the UK. Another cohort of entrants would pursue for diploma qualifications which are normally conducted by private higher institutions. Upon the successful completion of their first level of academic-oriented tertiary education, the qualified students would then be accepted to enroll themselves in one of the public or private universities in Malaysia.

Engineering Mathematics in UTM (a three-credit course with departmental code of SSE 1893) is taught as a service subject to all engineering faculties separate from the engineering context. It is designed to provide necessary knowledge and competencies required by students attending engineering undergraduate courses. At the Civil Engineering Faculty, UTM this Engineering Mathematics is taught in the second semester of the first year. UTM adopts the semester system whereby students will sit for their final examination at the end of their 14 weeks of study with 3 hours of lectures and 1 hour of tutorial per week. 50% of the marks are allocated for this final examination whilst another 40% will be made up of tests and quizzes and 10% allocation for assignments either done individually or as a group work. The engineering mathematics focus on the differential and integral calculus of multi variable functions covering the following topics: real functions of several variables, partial derivatives, multiple integrals, vector functions and vector calculus. The conventional style of lecturing compounded by the heavily packed syllabus taught within constrained time tend to emphasize the learning of facts and solving structurally similar routine problems using fixed mathematical procedures. This particular manner of learning mathematics was similar to their mathematics learning experiences in school with rote learning and drill exercises as the main modes of students' learning activities [25].

It is assumed that students are able to apply the mathematical knowledge and skills effectively in their respective engineering majors. To tackle their engineering problems or tasks, it is expected that students have acquired the mathematical essentials to identify and formulate them mathematically, to relate the mathematical knowledge and techniques, representations, skills and ideas to the engineering context [26], to work with multi-step procedures and adapt mathematical models to represent real engineering problems.

Unfortunately, findings from previous research have shown that the transfer of learning does not occur as efficiently as would have been expected [26]. In addition, students also displayed mathematical learning difficulties, for example, difficulties in coordinating procedures, manipulating concepts, poor recall and inefficient organization of known facts, and poor mastery of algebraic skills, mathematical language and symbols. As a consequence many students have difficulty in solving problems especially non-routine problems [26]. Research in recent decades in several different countries also demonstrated similar problem has continued to exist over the past four decades [27]. Apparently, there seem to be lack of motivation, lack of awareness for the relevance of mathematics in their respective engineering context, low self-confidence and low self esteem. However, the academic goal of critical and creative thinking instruction by furthering students in the development of their critical and creative thinking would increase the proficiency of students in interpreting, identifying, formulating, analyzing, evaluating and self regulating if effectively attained and appropriately applied. These skills constitute some of the cognitive skills central to critical thinking [15].

10.2.2 PRELIMINARY WORK ON THE TEACHING AND LEARNING OF ENGINEERING MATHEMATICS

Tying up between the students' mathematical inadequacies mentioned earlier and the current demands of the curriculum, the researcher has tried to create a supportive teaching-learning environment for the teaching of engineering mathematics by selecting a group of 64 students attending first year civil engineering undergraduates during their second semester. The students were divided into 10 groups randomly for a purpose that they should not be with their own cliché. It was hoped that some elements of adaptability among ethnic groups can at least be materialized in this classroom arrangement and that language should not be a barrier among these students. They set at 8 round tables except for two groups (as there were not enough round tables) during every lecture hours for almost throughout the semester. My first encounter with the students was a discussion highlighting the attributes and profiles of an engineer and demands of current employers. Some quoted extracts and excerpts from current researches and surveys on employers ratings were shown to the students. They were strongly encouraged to be in their groups throughout their semester during my lecture hours though they were not compelled to do so. They were encouraged to discuss with their group members all the exercises given in the lecture classes and to ensure that each and every member of the group understood the ways to solutions. I exercised minimal assistance to the students in getting those solutions to the given problems though I facilitated their understanding of the problem should the need arise. There were also times students were provoked with questions to shape up their understanding. At times students were asked to volunteer to come forward to explain their ideas to the whole class. Some of these activities were video-taped.

However, for every introduction to new topic, sub-topic, worked - examples and contextual tasks, the students were required to come forward and sat in the pre-arranged seats in rows in the front part of the classroom to listen and give full attention to all explanations and discussions before being allowed to move back to their round tables. Solutions to problems would be discussed after every trial the students have gone through before the next problem was given.

Students participated actively and cooperatively during lecture hours, most of them demonstrated good team spirits within the group with lively discussions. Apparently, they seemed much eased with peer coaching among them; the more able would readily discuss and try to convey their understanding of the subject and ideas to the less able. It was observed that there was much questioning among them as they moved through the problems trying to exploit their ability to visualize objects in three dimensional space. There seemed to be an air of enjoyment and self confidence as some would even walked about freely to voluntarily assist other members from other groups in solving the problems given.

10.3 OBSERVATIONS, ARGUMENTS AND ANALYSIS

10.3.1 THE GENERAL SITUATION

The wide variation in educational background among the entrants to the civil engineering courses at UTM has been a long time phenomena. STPM has their focus within a higher level of education program that places relatively greater emphasis on applications and problem solving on higher level understanding. This situation naturally poses distinctly different levels of capabilities amongst the students in the classroom. This calls for urgent need and proper measures to ensure that the most able students are not deprived of sufficiently developing critical and analytical reasoning skills to be at par with their counterparts elsewhere and at the same time to ensure that the less able have rewarding and relevant mathematical competencies at the appropriate level.

The context of acquiring knowledge appears to have a high tendency towards examination-oriented environment with almost 90% of the overall assessment being allocated for tests and examinations. The distribution of percentages seems to suggest knowledge acquired is in such a way to make it useful in the context of a structured exam; as Sternberg and Lubart [28] did mention once the exam is over, so is the use of the knowledge. Knowledge should be taught for use rather than for exams [28]. They further argue that the test students typically take reward them for spitting back what they have learned- or at best, analyzing it in a fairly noncreative way. Such teaching-learning environment does not inculcate healthy development of critical and creative thinking among engineering students who on the contrary need to be prepared to face novel unpredictable problems that call for sound critical and creative analysis.

More objectively, assessments should be efficiently distributed; it should as much encourage the nurture of other outcomes or skills being addressed. Assessments should appropriately include all forms of knowledge and skills acquisition. Felder and Brent [29] indicate that assignments which require independent literature and web searches helps develop the skill to find and organize information in the absence of texts and course notes. Students should be acquainted to contemplate approaches to solving problems much relevant to their subject area. In this way they learn to discern relevant and sieve out irrelevant information. To do this they need to be critical and creative in organizing facts and coordinating procedures and will be unconsciously blended with the skill of reasoning, formulating and translating information and meanings. This is especially true because when we think critically we are required to orchestrate a vast variety of cognitive skills, grouped in families such as reasoning skills, concept-formation skills, inquiry skills and translational skills [30]. These activities with fair acknowledgments would positively push the students to exert their potentials because engineering has its own motivation. Perhaps too they need to coordinate on multi disciplinary levels. Such activities characterizes so much of what engineers do in dealings at work where interactions and exchanges between architects, engineers from other disciplines, clients and others from different sectors are just unavoidable.

The normal practice of solving structurally similar routine problems using fixed mathematical procedures either during lectures or tutorials does not encourage the effective attainment of critical and creative thinking. As Felder argues that if students are assigned only well-defined convergent problems, they will never gain the skills needed to tackle and solve challenging multidisciplinary problems that call for critical judgment and creativity [3]. This is again emphasized by Sternberg and Lubart [28] that, if we want students to think insightfully, we need to give them opportunities to do so by increasing our use of ill-structured problems that allow insightful thinking. There are no fast, ready, expedient solutions to non routine or ill-structured problems. The difficulties encountered and the time taken to figure out the steps to solution is the hallmark of critical and creative endeavor. This is consistent with the indication given by the National Academy of Engineering [2] which states that the future engineering curriculum should be built around developing skills and not around teaching available knowledge. Sternberg and Lubart [28] further noted that if we want to improve our students and our nation, this is exactly what we need to do. In doing so, students should be given the opportunity to draw creative definition and redefinition of problems in the proper context. As such, students will develop insight skills and think insightfully.

The present teaching - learning environment seems to corroborate the rote learning and rote memorization behavior among the students which they carry from school to university. Bowden argues that currently, there is too much emphasis on quantitative problem-solving through rote-learned algorithms in isolated contexts. Students learn to solve quantitative problems by using the relevant rote-learned algorithm without necessarily understanding underlying concepts and without developing the capability to draw on their learned experience to deal with new, previously, unseen and, necessarily, more complex situations [27]. These problem solving tools are not useful if they are learned in isolation so that graduates are unable to work out critically and creatively; that is when and how to use them to deal with real-life problems. The context in which students acquire their knowledge is so different from the context in which they must use it that their knowledge is simply unavailable.

10.3.2 THE STUDIED SITUATION

It was observed the first encounter with the students helped them to realize the importance of acquiring those attributes and profiles of an engineer. The session did have some positive impact; it helped to shed some aloofness, exposure and insights for the students as they readily accept the idea of sitting in random groups.

Their attempts to strengthen their ideas by reasoning as they relate to the concepts previously discussed with reference to some methods and procedures adopted seemed to indicate some positive effect on the students. As Lipman [30], mentioned, these reasoning, methods and procedures are some instruments of the apparatus of rationality. When they are at work in the process of inquiry they function dynamically - and critically. They appeared to critically question each other as their understanding and visualization of three dimensional concepts developed. Their use of objects in their attempts to creatively illuminate the three dimensional ideas to their colleagues can help promote their critical and creative skills.

Another important advantage of converting a conventional lecture atmosphere to a community of inquiry is that the members of the community not only become conscious of their own thinking but begin looking for and correcting each other's methods and procedures. Consequently each participant is able to become self-correcting in his or her own thinking [30]. Accordingly, this atmosphere appeared to be encouraging for the students to exercise self-regulation as they consciously try to question, confirm and correct their reasoning and answers. As reported in the executive summary of "The Delphi Report", it was a strong consensus among the experts to include self-regulation as also central to critical thinking [15].

Additionally, peer coaching can add extra dimensions such as mentioned by Davies and Wilcock [31], that,

a. the cognitive processing used to study material for teaching-coaching differs from that used for studying for a test
b. peer learners benefit from their peers' ability to teach at appropriate levels
c. the students involved appear to benefit from the cooperative relationship that peer teaching engenders

All these activities blended together appear to constitute the ingredients for the promotion of critical and creative skills whilst self confidence, self-esteem, self awareness and high motivation seem to positively support the enhancement of these skills. This learning environment seems to promote students' self-confidence in their ability to reason and offer opinions to their peers. Though the study was not formally structured for proper engagement of critical and creative skills in the mathematics classes, nevertheless it seemed to have some significant changes in students' learning behavior. It is our belief that a better well objectively structured teaching strategy would bring forth the desired outcomes of critical and creative skills among the undergraduates civil engineering students.

Comments from students via short message system (sms) and e-mail seem to be consistent with the above benefits and the cooperative relationship has served to develop camaraderie among the group members. Students need all these supportive encouragement not only from their lecturers but also essentially from their peers to enhance healthy stimulating learning environment. The details of students' comments are available on request.

10.4 ROAD TO CHANGE

Teaching mathematics to first-year engineering students is a difficult task [32]. Academics must ensure that the basics are understood and well practiced but they also have to motivate each mathematical topic by illustrating how it connects or relates with ideas and topics within the students' engineering courses [32]. Manohavan et. al. [33] further states that to understand the mathematical methods and the corresponding solutions in an engineering field, engineering mathematics educators themselves should be able to see the connection between the mathematics and the respective engineering field. Responses from industrial players too states similar themes when McMasters and Matsch [34] emphasize that university administrators and faculty members need more knowledge of what industry does, how it does it, and what their graduates need to know to function effectively in an industrial environment.

These concerns can pose some difficulties to mathematics lecturers who are not familiar on many aspects of the engineering perspectives and engineering problems. As an initial attempt to address this matter, the researcher will essentially adopt a reasonably deep observation on the nature of engineering tasks in real context. For this purpose, we believe a close observation on the work of civil and structural engineers in real settings would be a rewarding effort for it could reveal a first-hand perspective of engineering tasks in particular the engagement and appropriateness of mathematical knowledge and skills according to the needs of the problems in context. These qualitative methodologies can be used to capture and quantify the extent of critical and creative skills involved in solving engineering problems and how they are nurtured among the new hires. Such observations can provide key data useful in determining the framework for the proposed instructional strategies which will be developed later.

10.5 CONCLUSION

What has developed in recent years is a realization that engineering mathematics is not simply 'service' teaching of pure mathematics techniques but requires its own motivation and skills focused towards engineering. These aspirations have been highlighted in two lMA conferences `The Mathematical Education of Engineers' organized at Loughborough University in 1994 and 1997 [14]. These conferences brought together mathematicians and engineers, academics and industrialists to establish a community and explore the current `best practices' in engineering mathematics. This has been reiterated by Hirst et. al., [32] when mention was made regarding the development in recent years pertaining to realization that engineering mathematics is not simply a matter of teaching pure mathematical techniques. It requires a direct focus towards engineering [35]. Hirst et. al., [32] acknowledge the difficulties face by the mathematics educators teaching mathematics to first-year engineering students. The situation is further compounded by the existing mathematical inadequacies among many engineering students. This is admittedly true when Yudariah and Roselainy [26] mention about their teaching having to address both the existing needs of the students and ensure their progress through the curriculum. This has compelled them to find teaching methods that would maintain a balance between helping students to overcome their difficulties and at the same time able to construct new mathematical knowledge and skills according to the demands of the curriculum.

The promise of effective attainment of critical and creative skills for an engineer is being able to make sound engineering judgments; recognizes key issues when addressing engineering problems, draws evaluation criteria from diverse sources and evaluates alternatives, makes decisions rationally and checks viability of decisions [30]. It is these proficient reasoning skills that ensure competency in creating alternative solutions, developing creative solutions, identifying, formulating and solving engineering problems and formulating a range of alternative problem solutions. It is crucially important that the teaching of engineering mathematics should sufficiently emphasize on empowering critical and creative thinking to help promote and widen students' horizon of understanding and seeing things; where it optimizes the quantity and quality of meaning engineering students perceive from what they acquire. Integrating these skills in the teaching and learning engineering mathematics to the undergraduate engineering students is thus of paramount importance.

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