Are Math-Oriented Critical Thinking Elements in Civil Engineering Workplace Problems Significant?: Insights from Preliminary Data and Analysis

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Abstract

The rapid pace of technological innovations in civil engineering is closely linked to the integrated symbiosis between mathematics and civil engineering. This would demand civil engineers to be competent and reliable in their mathematical and engineering manipulations, evaluations and interpretations. Moreover, to confront real world socio-civil engineering scenarios such as construction disasters, civil engineers have to critically discern information, make decisive judgments and draw rational decisions which may be based on sound mathematical knowledge and skills. This paper intends to describe a study carried out at a civil engineering consultancy firm with the aim of getting an overview of some prevalent trends of civil engineering problems that may require the engagement of math-oriented critical thinking (MOCT) elements to solve. Exposures to the experiences and engagements of practicing civil engineers at the workplace can offer broader insights to mathematics educators teaching engineering mathematics to civil engineering undergraduates of the nature of civil engineering problems in their real context, and workplace challenges. These exposures inevitably may lead to the exploration of the MOCT elements embedded in solving these problems. Less technically, MOCT skills can operationally be defined as a continual process that involves acquiring and using an appropriate set of math-related cognitive skills which are affectively driven by dispositions that promotes and reinforces such skills. The findings may also advise mathematics educational endeavors to integrate authentic problem-solving experiences for civil engineering students.

Keywords: *elements of critical thinking, math-oriented critical thinking elements, and trends of civil engineering problems.*

1. Introduction

One of the worst tragedies in the history of Malaysian construction industry was the collapse of Block 1 Highland Towers Condominium in 1993 which claimed forty eight lives and tremendous loss of properties. Recalling other construction disasters includes the massive landslide in 2008 which destroyed fourteen bungalows and killing five people, the collapse of a giant supermarket during demolition works in a busy commercial district and the collapse of the RM292mil Sultan Mizan Zainal Abidin Stadium's space frame roof structure in 2009. One could just imagine the extent of the catastrophic disaster that could have occurred should the stadium was in full use at the time of incidence.

Whatever the reasons could be for the many construction disasters, be it poor quality materials and workmanship not up to specifications, poor design or poor quality control at construction sites, civil engineers would be among the first key technical experts called for to give professional opinions and constructive suggestions to correct and eventually evade such engineering frailties in the future. The soundness, competencies and reliabilities in their civil engineering manipulations, analysis, synthesis, evaluations and interpretations would be called for to safeguard public interest, safety and properties.

These circumstances indicate the vital need for civil engineers to possess the critical thinking capabilities to discern information, make assumptions, make decisive judgments and finally draw informed and reliable decisions. Furthermore, civil engineers need to design, develop, innovate and integrate ideas (ASCE, 2008) in their decision making encounters where habitual or routine processes may not be easily developed to find solutions to problems under these uncertain situations.

Additionally, engineering practice will be challenged to shift from traditional problem solving and design skills toward more innovative solutions (Dudderstadt, 2008). This is a significant challenge for civil engineering industry where innovation and integration of ideas and solving problems (ASCE, 2008) would not only be embedded in environmental issues but also in an array of other issues including social, cultural and ethical issues (Dudderstadt, 2008). The critical thinking abilities of a civil engineer would allow a far more holistic approach to addressing these social needs and priorities of their socio-civil engineering problems.

The integral relationship between mathematics and civil engineering has long been established. Historical findings reveal this integral closeness with astonishing discoveries such as the monolithic monuments; the Stonehenge in England (http://en.wikipedia.org/wiki/Stonehenge) which were constructed over 5000 years ago. Another striking example is the discovery of the Egyptian pyramids in approximately the same era. These examples give testimony to the fact that prehistoric peoples must have had some knowledge of geometry linked to some form of construction engineering. Moving through the passage of time, these relationships developed tremendously to the extent where the symbiosis between mathematics and civil engineering is so well establish that the complexities of problems in the civil engineering world demand civil engineers to be sound, competent and reliable in their mathematical and engineering manipulations, evaluations, interpretations and innovations.

New subfields in engineering ranging from one extreme to the other such as nano-technology to mega infrastructures continue to emerge with an infinite range of exciting new technologies which await development by engineers who are fluent in mathematics. In order to align with the future transformation of engineering education for the 21st century, a conscious and sustained effort is needed to convey the opportunities and excitement mathematics can offer to prospective civil engineers. While preeminence to all technological innovations is sound mathematical knowledge and skills, a successful innovative engineer is the one who most likely equipped himself/herself with substantial knowledge of mathematics (Moussavi, 1998).

A review into the Body of Knowledge for the American Society of Civil Engineering (ASCE, 2008) reveals that the cognitive level of achievement has been generically described base on Bloom's taxonomy and the associated descriptors for the civil engineering courses have also been specified. However, there are no clear descriptions delineating critical thinking elements for the mathematics course in civil engineering. In fact, the committee has indicated the desirability for any research endeavour to engage into areas relating to exploring the affective domain of learning for all civil engineering courses (ASCE, 2008).

These aspirations and current advancement in knowledge and technology, has aspired the Engineering Accreditation Council for the Board of Engineers of Malaysia to emphasize on critical thinking skills development, and evidence-based decision making in the curriculum (EAC|BEM, 2007).

Unfortunately, the absence of clear descriptions delineating critical thinking elements for the civil engineering courses and compounded by the varied interests and needs of each university can again lead to various ways of expressing the critical thinking skills requirements.

An Engineering Professors Council for the UK reported that such environment can lead to difficulties in communication between those who need to be absolutely clear amongst themselves about the standard of an engineering graduate at the output of his or her degree programme (EPC, 1997). Facione et. al.(1995) express concern that it would be impossible to understand the teaching of critical thinking without an appreciation of the characterological profile of the kind of individual one was trying to nurture.

Reflecting on the MOCT skills, less technically, MOCT skills can operationally be defined as a continual process that involves acquiring and using an appropriate set of math-related cognitive skills which are affectively driven by dispositions that promotes and reinforces such skills.

It is strongly felt that, the significant relevance of a study to grasp an overview of some prevalent trends of civil engineering problems and workplace challenges that may require the engagement of math-oriented critical thinking elements to solve is fervently appropriate. It is fundamental to understand the nature of civil engineering problems from the perspectives of civil engineering industry as the real world experiences of these professionals would reveal authentic scenarios. This requirement primarily lead to a preliminary study of exploring the experiences, exposures and engagements of practicing civil engineers at the workplace.

The findings entailed from this study would offer insights to educational civil engineering communities the prevalent trends of civil engineering problems and workplace challenges that may require the engagement of math-oriented critical thinking elements to solve. Besides, these findings can bring potential awareness to educational instructional designers of the math-oriented critical thinking elements essential during the training of civil engineers.

2. The Definition For Math-Oriented Critical Thinking Skills

For the most part, conceptualizations of critical thinking have been approached from the philosophical stance (Douglas, 2008). That is, the definitions are not rooted in empirical studies, but rather in philosophical rationale about what critical thinking is or ought to be. Some of the most well known conceptualizations are those of Ennis, Paul, McPeck, and Martin (for a review, see Mason, 2007 cited by Douglas, 2008). Another approach that appears to be close proximity to an empirical definition is that of Facione (1990) who in the Delphi Project headed the inquiry into critical thinking and critical thinking assessment. The national panel of experts in this project reached a consensus to encompass two dimensions in critical thinking, that is the cognitive skills dimension and the affective dimension, namely the dispositional dimension (Facione, 2007). They unanimously reached a consensus to include the skills of interpretation, analysis, evaluation, inference, explanation and self regulation as essential cognitive critical thinking abilities (Facione, 1990, 1995 & 2007Update).

The above discussions lead to the operational definition of MOCT for this research. MOCT for this study would involve acquiring and using an appropriate set of cognitive skills and affectively driven by attitudes and habits of mind that promotes and reinforces such thinking. This includes attitudes of being disposed to open-minded questioning, critical reflection, zealous dedication for knowledge and reasons and, eagerness for reliable information (Ennis, 1987). It also includes the idea that the effectiveness of critical thinking must be translated into actions and applied to other areas of practical concern (Ennis, 1987). The following definition is proposed:

Math-oriented critical thinking is a continual process that begins with the appropriate attitude of being disposed to open-mindedly gather, analyze, interpret, evaluate and synthesize information, arguments, reasons, ideas, solutions or beliefs, using an appropriate set of cognitive skills that leads to reflective appraisal and results in actions applicable to areas of concern. On the micro level, critical thinking sub skills, would include such skills as comparing, contrasting, conjecturing, inducing, generalizing, specializing, classifying, categorizing, deducing, visualizing, sequencing, ordering, predicting, validating, proving, relating, and patterning.

3. Why Critical Thinking? Critical Thinking In The Context Of Malaysia's Vision 2020 And Why It Is So Important In Civil Engineering?

Forbes [13] (1997) in describing the breadth of failure in the American education system – in terms of academic achievement, social equity and graduating citizens with the ability to think critically and act ethically, mentioned significant related instances due to this failure in critical thinking. She further remarked that the one common denominator to all of the noted incidents is that most of the people involved in these actions and decisions are products of the American education system. This system was a part of this failure in critical thinking as well as ethical leadership (Forbes, 1997). These are just some examples which could exist anywhere else where critical thinking has failed to play part of the contributing factor in educating citizens to be responsible and accountable for their actions.

The rapidly changing technology and increasing pace of economic globalization has provided the impetus for critical thinking and other professional skills to be ever more critical. Malaysia's Vision 2020 has as one of its aspiration for critical thinking to play an important role in the development of the nation's economic benefits driven by a mature Malaysian society. It prominently reflects the awareness that such ability to think critically can well contribute to the nation's successful developments economically and ethically. For example, as Mahathir Mohamed (1991), the former premier of Malaysia mentioned, citizens benefit from higher level thinking by being able to develop and formulate intelligent judgment on public issues; thus contributing democratically to the solution of social problems.

Thus, a nation with skillful technological workforce and citizens who can think critically would be valuable assets for economic and social development as Paul (1994, pp. 22) remarked; "*Then not only would we have a large pool of talent to solve our technical and scientific problems, but we would also have a citizenry with the critical faculties and intellectual wherewithal to recognize and prevent wrongful and wasteful allocations of life, money and other resources*".

In the light of moving toward an industrialized nation, the Malaysia Vision 2020 explicitly stated that Malaysia will become a fully developed industrialized nation by 2020. As time passes Malaysia like many other industrialized countries has come to a stage where precision-oriented, custom-tailored, and technology driven skills are much sought for (MITI, 1996). Indeed, this most highlighted 'mission statement' for the country calls for the imperative development of highly skilled manpower (OECD, 2008) with the capacity to think creatively and critically, solve problems effectively, make insightful and thoughtful decisions and able to adapt and adjust to future uncertainties.

Globally too, the demand for human resources is accelerating (OECD, 2008). The current growth of knowledge and economic intensity implies an increasing need for highly skilled workers (OECD, 2008). A nation with skillful technological workforce imbued with all the essentials of critical thinking skills, would warrant effective and efficient support for rapid development. For example, civil engineers need to design, innovate, develop and integrate efficient and effective system of transportation, construct efficient and effective drainage system, minimize any hazardous environmental setbacks at construction sites and so forth.

Thus, the mastery of critical thinking skills besides other professional skills combined with the ability to innovate will add sufficient value to the civil engineering industry in making the Malaysia's Vision 2020 a reality. One could feel the impeccable impact critical thinking has over civil engineering when civil engineers will be one of the key technical experts being called for to address all construction disasters. They are expected to collectively find solutions with other multidisciplinary experts to evade such engineering disasters in the future.

4. Research Conceptual Framework

This study is informed by reports, theories and researches relating to preparing future engineers in the light of the rapidly changing world as immensely reported by the National Academy of Engineering (NAE, 2004; 2005), the Royal Academy of Engineering (Spinks, 2008), and the Millennium Project (Duderstadt, 2008). This conceptual framework also incorporates some important components of critical thinking skills as propagated by Facione (1995, 2007) and Ennis (1991, 2008), and drawing ideas from the socio-constructivist learning perspectives.

4.1. Engineering Perspectives

Reports of Engineers 2020 (NAE, 2004 & 2005), the Millennium Project (Duderstadt, 2008) offer an overview of what the engineers of today and tomorrow would have to face in this rapid-paced challenges of the knowledge-based global economy of the 21st century. The world today is facing fast technological innovations and reciprocal social challenges such as information and communication technology explosion, cyber crimes, health and increasing fatal diseases, threatening life and death rate, threatened national security, and to the extent of using sophisticated war artilleries which can also kill many innocence. As time passes our engineers will have to face even bigger challenges which would require them to solve not only local problems but as well global problems of unprecedented magnitude and scope.

A glimpse of what the engineers need to be able to do in the coming years found in the reports of Engineer 2020 (NAE, 2005) and the Millennium Project (Duderstadt, 2008) reveals the essentials of critical thinking elements well embedded in the key attributes of an engineer. In what follows next, are descriptions pertaining to the ingredients of critical thinking which covers both the cognitive and the dispositions towards critical thinking. It is expected that engineers need to possess strong analytical skills, exhibit practical ingenuity, master the principles of business and management, understand the principles of leadership, dynamic, agile, resilient and flexible to changes, and able to apply knowledge to new problems and new contexts and being lifelong learners because the career trajectories of engineers will take on diverse and dispersed directions (NAE, 2005; Duderstadt, 2008).

4.2. Critical Thinking Perspectives

While the views of other proponents of critical thinking are not to be denied, this research draws upon the critical thinking perspectives described by Facione et. al. (1990, 1995 & 2007) and Ennis (1987, 1991) which encompass two dimensions in critical thinking, that is the cognitive skills dimension and the affective dimension, namely the dispositional dimension. These perspectives suggest skills and dispositions are mutually reinforced and, hence, should be explicitly taught and modeled together.

Motivational theory (Lewin, 1935 as cited by Facione et. al., 1995) provides the theoretical grounds for the assumption that the disposition to value and utilize critical thinking would impel an individual to achieve mastery over critical thinking skills, being motivated to close the gap between what is valued and what is attained. Whilst Ennis (1991) gave greater prominence on the importance of critical thinking dispositions besides giving a more explicit emphasis on the importance of knowledge in the area in which the thinking occurs.

Ennis (1987) emphasized on the ability to integrate facts and concepts acquired and later translated and effectively transferred in new situations.

Besides consisting of an interactive panel of forty-six experts recognized by professional colleagues as having special expertise in the area of critical thinking, another strength of the Delphi Project is the way of reaching consensus among the experts involved which is not a voting or tabulating process. The national panel of experts in this Delphi Project unanimously consented to include the skills of interpretation, analysis, evaluation, inference, explanation and self regulation (Facione, 1990, 1995 & 2007) as essential critical thinking abilities. The discussion of this paper would only focus on the cognitive aspect of critical thinking which is not meant to deny the important emphasis of the dispositional aspect.

It is important to note that the concepts outlined regarding the work of Facione et. al. (2007) and Ennis (1987) are discussed here as complementary and overlapping. Although these sets of critical thinking skills are non-content specific, but they do offer close congruency to the general standards of achievement of engineering graduates as outlined by local and abroad engineering bodies and accreditation councils such as the Accreditation Board of Engineering and Technology, USA, (ABET, 2000), American Society of Civil Engineers (ASCE, 2008), the Engineering Professors Council, UK, (EPC, 1997), and Board Engineers of Malaysia (BEM, 2007).

Being closely congruent to the general standards of achievement of engineering graduates, these sets of critical thinking skills are also in close proximity to the Bloom's Taxonomy which provides a comprehensive Body of Knowledge Outcome Rubric (ASCE, 2008) for civil engineering. In defining the Outcome Rubric, Bloom's six levels of cognitive development were referred without modification as levels of achievement (ASCE, 2008).

4.3. Social Constructivist Perspectives

This study also draws upon the ideas from social constructivist perspectives. Wertsch et al (1995, p. 11) defined the goal of a socio-cultural approach of learning as follows: "*to explicate the relationships between human action on the one hand, and the cultural, institutional and historical situations in which this action occurs, on the other*." From this perspective, it implies that the surrounding environment which may include the cultural, social and institutional aspects independently influence the process of learning. This more holistic approach holds that the social activity of learning fuses both the cognitive and affective processes. This socio-cultural approach maintains that the affective dimension of learning is of equal importance as the cognitive one. Moreover Wertsch (1985) earlier noted that the genetically determined capacities of an individual can be modified and (re)organized into higher mental forms through interactions with others. This indicates that the learner and the social and cultural influences surrounding the learner contribute to the effectiveness of learning. This would mean that to nurture critical thinking skills effectively among learners, both the cognitive and the affective aspects need equal emphasis which is coherent with the critical thinking perspectives as drawn by Facione et. al. (1990, 1995, 2007) and Ennis (1987, 1991).

5. Methodological Framework

A deep and genuine curiosity about understanding the task and experiences of civil engineers in their real setting is appropriately relevant. It is the "inner worlds or the subjective worlds" (Johnson & Christensen, 2000) of a civil engineer; the values uphold, beliefs, thoughts and attitudes that strongly shape and influence their observable practices. The best approach to gain access to this intimate domain of data is through a close-up observation and inquiry. Thus a qualitative nature of study is the best way of representing the multiple realities and experiences of the civil engineering world.

Indwelling as close to the construction of the real world of civil engineers would also minimize the unfamiliarity of many aspects of civil engineering perspectives and civil engineering problems to the researcher. As Maykut and Morehouse (1994. pp 27) exert, a qualitative researcher learns about significant aspects of reality by indwelling in complexities of human persons or activities. Besides, the purpose of observations at this stage facilitated preparing the appropriate questions for interviews at later stages of the research. Questions and short field notes were noted down to help provide further information as the observations were carried out.

Moreover, close-up observations and inquiries such as interviews would allow and healthily promotes critical reflection on the experiences and circumstances of these civil engineers in their real contexts. Adhering to Corbin's advice (Corbin and Strauss, 2008), the researcher needs to feel the experiences through the eyes of these participants. These close-up observations and inquiries would help the researcher to develop a better understanding of the broader social context of human mental processes and their situated features (Corbin and Strauss, 2008). Semin (in Lave and Wenger, 2003) coherently noted that an understanding of human cognition and cognitive processes cannot be explored in a framework that detaches mental activities from the socio-cultural settings of the participants.

Inspired by the above curiosity and driven by the research aim, this initial inquiry was carried out at a civil engineering consultancy firm. This preliminary exploration was undertaken to get an overview of the nature of civil engineering problems and the math-related critical thinking elements involved in solving these problems. Interviews and observations were carried out on these civil engineers at the firm's office on their design work, at construction sites and in their technical meetings.

Interviews were semi-structured with each interview ranging from one hour to one and a half hour with open ended questions. Questions were focused on the general overview of the stages involved in projects, general questions about their experiences relating to challenges, constraints and difficulties encountered, the mathematical aspects such as variables considered, establishing relationship between these variables, mathematical approaches applied in their design drawings and overall solutions to solving their engineering problems. The interviews were recorded using a digital audio recorder and transcribed verbatim. Also, the first author and primary researcher photocopied some design-related documents as artifacts of mathematical activity for a subset of their daily discussions at the firm's office.

The interview transcripts were analyzed using a constant comparison methodology in the interviews the participants discussed different "things" they had experienced and encountered. Each of these "things" that relate to the research questions was considered a theme. As the investigator read through the transcripts, each of the "things" that a participant mentioned was compared to the themes that had already emerged, and the "thing" was either categorized with a pre-existing theme or used to create a new theme. The categorization was done by a single coder. In this preliminary report the results from interviews on only two civil engineers will be discussed. Additional interviews and analysis are currently ongoing and will be discussed elsewhere together with results from observations.

6. Qualitative Analysis Of Interviews

Coding the interview transcripts began by examining the interview protocols for salient themes of information and then identifying categories for these themes of information. The coding of the categories was a means of establishing the themes during the process. With the aim of getting an overview of some prevalent trends of civil engineering problems that may require the engagement of MOCT elements to solve, this report coherently present the analysis of a preliminary study on the nature of civil engineering problems in their real context, and workplace challenges. This analysis is based on interviews done on two civil engineers; a professional practicing civil engineer with a vast experience of more than twenty years and a young practicing civil engineer with an experience of four years.

6.1 The Professional Civil Engineer: Ir Amir

With a masters degree in construction management from one of the local institution of higher learning in Malaysia, Ir Amir (hereafter referred to as CE 1) has had an overwhelming experience of more than twenty years in the civil engineering industry. His designation as a professional civil engineer has given him the opportunity to work at many different places which includes the Public Works Department at an army base, land and property developer, Perbadanan Lebuh Raya Utara-Selatan (PLUS) that is the Malaysian North-South Expressway, a contractor firm and currently working as a consulting engineer for project management at a civil engineering consultancy firm. Through these working years, he has developed a wide spectrum of accumulated experiences, exposures and expertise. At the time of the interview, he is involved in two national mega projects as a design and project coordinator for the approximately RM5bil double-track railway construction project running from Ipoh to Padang Besar, Malaysia whilst the other engagement is an expressway project from Ipoh-Gua Musang to Kuala Berang, Malaysia.

6.2. The Young Civil Engineer: Engr Hamdee

Engr Hamdee (hereafter referred to as CE 2) graduated with a masters degree from one of the local institution of higher learning in Malaysia. With a few years of involvement in the civil engineering industry, this young practicing civil engineer has engaged himself with a few small and medium sized projects ranging from RM1mil to RM50mil. His work has carried him through designing and managing construction buildings and infrastructure and at the time of interview he was involved in the design and construction of a RM22mil project of building a faculty for one of the local universities.

In what follows are the major themes and categories that have emerged from the interview data to date.

Category 1. Workplace Problems are Not Well Defined

A salient feature of civil engineering workplace problems is that they are not well defined. The natural terrains, realities and constraints at the sites can add further complexities to the initial tasks making it more ill-structured. There are many instances revealing this theme but only some will be recounted from the interviews as quoted below.

Talking generally on design work, the following responses were noted;

CE 1: "I'm mostly involved on the conceptual aspect of the design work, not much detail. I'm involved in conceptual and towards implementing on site what has been designed. There is possibility in the transition from what has been designed and the implementation on site, that there is a need to readjust here and there. For example, in the present double track railway project, being the coordinator, I have to understand what is needed and what fits at the site. When we bring to the site, there are things to be realigned here and there."

At a point of discussion related to designing the speed of vehicles in road construction, CE 1 has the following to describe with reference to natural terrains, realities and constraints at sites which can add further challenges;

CE 1: Look at this curve from the horizontal alignment on plan. If there is a hill nearby or a river here, we have to avoid. When we avoid these, we have to take into account this curvature."

In the double track railway construction project, CE 1 mentioned that there are swing bridges at various places besides sixty-six bridges to be constructed with some as short as between three to four meters long while the long ones can reach up to fifty meters in length. Workplace engineering problems can be ill structured with environmental features in nearby construction sites that can pose challenging constraints to these engineers as recounted by CE 1 on the double track railway construction design project:

CE 1: "And this is the Prai River. One section of the bridge can be rotated over here. It can swing. This is quite a wide river, and we have to allow for marine passage where boats can ply along under the bridge. But sometimes the height of the boats does not permit because this is a very low bridge. So this part of the bridge needs to swing to here so that when its' open, it will provide the passage way for the boats to go through here. Ok, when the train needs to cross over, the bridge will swing back here. So the boat will wait here in the navigation channel, and then it takes about fifteen minutes to allow for the train to cross over. So, that we have to take care of."

When asked as to what they have to take care of? CE 1 responded:

CE 1: "We have to accommodate for two tracks, track number one and track number two. During construction, this one (swing bridge) must be in operation. The consideration is when the bridge swings, will it touch this one (tracks under construction) or not?"

To a question asked why the location of the new tracks is closely built to the former rotatable bridge, CE 1 has the following response:

CE 1: "Very close...reason being, this is a very expensive area...the container yard around here... Penang Port is close by… a whole lot of variables...the ferry jetty is just here... so that's a lot of issues to consider…"

From the above excerpts, mathematical calculations and manipulations are just ubiquitous throughout the project from the very beginning when the engineers initially start the design process to realigning the design when faced with realities and constraints on actual sites. Their mathematical calculations and interpretation of the results has to be highly exact and accurate to avoid any fatal injuries.

Category 2. Non Engineering Parameters

Complexities of workplace problems are compounded by some constraints which are non civil engineering in nature. Whilst designing and constructing the double-track train project for the section running from Ipoh to Padang Besar in West Malaysia, these engineers have to face multi facets of complexities that comprised of sets of problems which were a combination of engineering and non engineering problems. These can be felt in the quotations described by CE 1 pertaining to the many surrounding constraints within the intended construction sites in the double track railway construction design project.

CE 1:"..actually, there are many constraints around here, there is a pharmacy,..school..everything. There is no construction yet, just starting the setting. There is a hospital, a temple..a school..".

In another excerpt, CE 1 provided the following example for this theme:

CE 1: "… this is a very expensive area...the container yard around here... Penang Port is close by… a whole lot of variables...the ferry jetty is just here... so that's a lot of issues to consider..has yet to accommodate for the ferry..."

Although civil engineering problems can involve non-civil engineering parameters, but it is unavoidable that engineering problems can be intertwined with civil engineering problems which may call for mathematical analysis to effectively solve the problems. Besides, the critical thinking abilities of civil engineers would also allow a far more holistic approach to addressing these social needs and priorities of their socio-civil engineering problems.

Category 3. Commonly Followed Code of Practice

Since the construction Codes of Practice represent the base knowledge of normal practice among the civil engineers at the firm, much of the analytical aspects done throughout the construction process lies in interpreting these codes. There are compromises which the engineers have to do although the Public Works Department (JKR as in Malaysia) has set the framework technical guidelines. Civil engineers need to understand and extend the meanings of these codes using the same "language" and style as the codes do. These codes offer equations that these engineers can make use of. Additionally, working within the codes, designs calculations will be familiar to other engineers and to other official building inspectors. The following excerpts illustrate this theme.

In the road construction design projects, civil engineers need to inspect the cross sectional drawings for every stretch of the road construction design. They have to know the criteria for the design alignment and profile. For example, for one kilometer stretch of road over a hill, as CE 1 mentioned, civil engineers can design variation of gradients in vertical alignment up to level 7.

CE 1: "We have the vertical alignment and the horizontal alignment. Horizontal alignment will be on the plan. This is the very basic. For a hundred meter stretch of road, the gradient can increase to seven meters. JKR has set these guidelines. They call it the framework technical guidelines."

To a question asked whether civil engineers need to identify the variables and set up the relationship between these variables involved in building roads, the response was as follows:

CE 1: "Oh yes. In the design. Actually, these things are already there. We just have to follow. Now, engineers more on design according to the… for example, code of practice or..technical order".

When discussing on the relationship between speed and radius of curvature in road construction design, CE 1 has the following descriptions:

CE 1: "We have set the design speed, meaning to say there is a formula…Formula relationship between the design speed and radius of curvature. There is a relationship. If we look into the book, highway engineering, this is very basic...".

The second civil engineer gave another relevant example:

CE 2: "For example, we want to design a column. We times by its factor. All the loading above will be multiplied by their factor. All those factors are in the code and has been specified how much the factors are."

To a question asked what determines the quantity of factors to be multiplied, the response was as quoted below:

CE 2: "That is in the code. Follow the code. We have to multiply by those factors the code has given, we just follow, we just follow..1.4, 1.6…"

Although the Codes provide recommendations for the practical design of structures, concrete, steel, etc yet a convincing argument is essentially needed to show that a structure will behave as predicted, and this may be in the form of mathematical analysis and require the input of sound mathematical background.

Category 4: Often Encounter Unanticipated Problems

Problems can be very dynamic in nature and they can change over time. What makes the problems more complicated is when these engineers encountered unanticipated problems when it comes to the implementation of the design at the actual sites. These may be a mixture of civil engineering and non civil engineering in nature. In describing road construction design projects, these brief responses from CE 1 illustrate the occurrence of such problems.

CE 1: "There are things that are not within the book. Theory is from the conceptual aspect..but when you go to the site, maybe there are houses, government reserved land, you can't even get access to the site."

CE 1: "Sometimes we have to build the road this way.. *'sengetkan dia'* because there is a relationship between the weight of the car, surface resistance and what we call the centrifugal force. And there are many other considerations that we have to look into.

CE 1: "..but when comes to the implementation for the road construction projects, there are many other things like…"

Similarly to the ill-structured nature of civil engineering workplace problems, unanticipated problems at actual sites would demand civil engineers to be critical and innovative in finding alternatives to solve their problems which may call for sound mathematical analysis, interpretation, evaluation and synthesis of the results.

Category 5: Collaborative Effort with Other Sectors

To achieve success in all their projects, they need to inculcate healthy interactions with many others from different sectors. Collaborations are most successful when they have harmonious working relationship among the personnel involved besides sharing a common goal. Civil engineers must collaborate with other personnel of diversified expertise in order to successfully identify and solve their socio-civil engineering problems. There is the need of the client that they have to satisfy, the economical aspect, time constraint, the esthetic taste of the architect versus the engineers' safety factor which cannot be compromise, the restrictions and rules of the local councils that they have to satisfy and comply with, the building contractors, and of course the need to extensively collaborate with other verified multi disciplinary engineering expertise. In all construction undertakings, to maintain the budget set forth for the projects is a significant priority. During the process of the railway double track construction, the civil engineers need to decide whether to demolish buildings that come underway of the railway track construction and relocating these buildings. The following excerpts reveal the essential interactions and collaborations between civil engineers and people from other sectors to achieve decisions to their best interest.

CE 1: "The train just started to move from here. Start moving..just getting the acceleration. So we would need this kind of curvature because it is just starting to move. So, initially, the speed of the train is not that high. When the speed is not that high, it means that we don't need to have the railway track very straight. The radius of curvature can be 200m instead of 600m. The smaller the radius of curvature the more curve the track will be..but now the train is not travelling at very high speed..it just started, so we can compromise what is there on site, that is we can accommodate instead of demolishing all the things to straighten the way.. for example these buildings here. But, if we follow the original alignment, this part need to be demolished..so if we say we want to compromise since the train just starting to move, then we can do with a shorter curvature."

To a question of who finally decides to the above mentioned problem, CE 1 responded which distinctly suggest the above theme:

CE 1: "Its' a pool of people involved; from KTMB, we the engineers, ministry of transport, they all must understand the whole concept first before making the decision."

CE 1: "Everybody. The operations, the engineers, the present architect of the building.."

To another question asked on the construction of the railway double track across the Bukit Merah Lake, CE 1 recalled the different personnel involved in making the project a success:

CE 1: "For this new structure, we construct a marine structure across the lake, so we called people from the marine structure. If it is a bridge, we called those from the marine via duck. We have to do soil investigation. The geo-technical engineer has to recommend. He will inspect the ground profile."

In another example, the young civil engineer working on a design problem recounted:

CE 2: Sometimes when we go to the site, those contractors don't understand. So, we who understands have to rectify the matter.

Category 6: Civil Engineers May Rely on Their Past Experiences to Solve Problem

Solving problems in school begin with the conceptual understanding of the subject matter and formulating the problem into conceptual model of the subject domain. However, their conceptual knowledge and understanding becomes embedded in their experiences as the learner gains experience through solving similar or new problems. They benefitted from their previous knowledge of the problems they have solved in the past rather than relying much on their conceptual knowledge.

Similarly with civil engineering problems, experienced civil engineers tend to rely more on their past experiences as these experiences can suggest ways to solutions. The following excerpts illustrate this theme.

CE2: "Maybe he did it through his experience….used to already..no need for the codes."

In contrast to young inexperienced civil engineers, CE 2 again recalled;

CE 2: "I don't have the guts yet..because I'm afraid..that's why I'm concerned of the safety…let, let it be big..never mind of the many iron rods…I don't care..though won't look nice..I don't care..importantly, as long as it is safe.."

To a question on making the best decision when working on a design problem, CE 2 recounted;

CE 2: "Its' not wrong, not wrong..we have the calculation, full calculation. Its right what we've done..so, which one is the best? Maybe I can't get which one is the best..it depands on experience too…but..we're not wrong. Maybe..I can't make the best decision."

7. Conclusion

As a respond to our question: Are math-oriented critical thinking elements in civil engineering workplace problems significant? We answer in the affirmative! Although this qualitative study is only at its preliminary stage, we have identified some of the prevalent trends and challenges of civil engineering problems at workplace in their real contexts. These themes and categories includes workplace problems are not well defined, workplace problems can encompass non engineering parameters, problems are solved by commonly follow Code of Practice, often encounter unanticipated problems, need collaborative effort with other sectors and civil engineers may rely on their past experiences to solve problem.

In most of the themes identified, it is worth noting that the use of mathematics is widely applied in civil and structural engineering problems. The 'pure' mathematical meanings seems to be implicitly hidden and embedded behind the 'civil and structural feel' of the problems, but it still remains relevant to know where analytical results come from. The expressed clusters of responses strongly seems to suggest that MOCT elements are significantly essential to support the analytical ability of civil engineers, to increase their ability to interpret, evaluate and integrate results, and thus increase the sophistication of their decisions on well informed arguments. Thus we conclude that math-oriented critical thinking elements are significantly needed to solve civil engineering workplace problems.

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