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Letter to Editor

MALAYSIA CIVIL ENGINEERING EDUCATION IN THE 21ST CENTURY: A PERSPECTIVE AND THE PROPOSAL FOR A NEW MODEL

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Abstract

Recent events have inspired me to put on record the thoughts I have regarding civil engineering education. It revolves around the observations I made for the past two decades and how civil engineering education in Malaysia might need a new perspective and framework. The keyword for the new framework is commonality. In System and Process, commonality can be defined as "the common elements of a process that facilitate the definition of a family of processes through reuse". But I will use the term in the context of civil engineering education the way I perceived it. However, my writing is not based on exhaustive scientific data or survey but as mentioned, mainly derived from my observations, thus a hypothesis, at best. After I set the scene, I then propose and detail the new framework for civil engineering education which I believe suits the 21st-century aim of producing resilient, and holistic civil engineers.

Keywords: Civil engineering education, EAC-BEM accreditation, Outcome-based education, Active learning, Deep learning

1.0 INTRODUCTION: IT USED TO BE ALL CLASSICAL

My undergraduate study in Civil Engineering (CVE) at Universiti Teknologi Malaysia (UTM) was in the 90s, 1995 until 1999, to be exact. It was all classical with almost no contents on engineering software. The best exposure I had to the Finite Element Method was in an elective course focused on the direct stiffness and flexibility methods (so, it was not really FEM). However, we knew at the time that various software being used in the engineering office. It was almost a consensus that you learn software when you start working, and you learn it from your senior engineers.

2.0 THE 1ST DECADE

I was appointed as a tutor at UTM almost immediately after I graduated. Such appointment has given me the opportunity to witness the greater emphasis put on the use of engineering software in the CVE syllabus, a process at the dawn of the 21st century. This act was great as it was what needed. Was there a trade-off due to such an inclusion? None as I remember. Maybe, the domain of CVE education at the time still able to absorb newer contents. Perhaps, some small tweaks have optimized the system in accommodating such enhancement.

In the mid of the 1st decade, we were required to satisfy the EAC Accreditation. With it came Outcome-Based Education (OBE); outcomes attainments (e.g. PEOs, POs, COs), complex engineering problems and activities (e.g. WPs and EAs), knowledge profiles (e.g. WKs), and Bloom Taxonomy (e.g. cognitive, affective, psychomotor). Was there a trade-off? I believe none on the receiving end (students' end). Instead, it can enhance if properly and correctly implemented. But surely there were trade-offs on the giving ends; many academics shorten sleeping hours. But as teachers, we did not mind. We are trained not to mind when it comes to student's betterment.

I could see where this was coming from. With the exponential development of knowledge and technologies, we need to tidy up and optimize the learning and teaching (L&T) process. We need to align things constructively, hence the term constructive alignments. But OBE is highly conceptual (if not philosophical) yet technical. Take PO2 for example [1]:

PO2: Problem Analysis - Identify, formulate, conduct research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences (WK1 to WK4)

What does it mean? Every single term deserves a discussion. What and why “identify, formulate”? Should the two co-exist, or either one is sufficient? Must all courses addressing this PO, conduct a literature search? How low should one descend to work from first principles? Is it the differential or integral equations? Is it the conservation laws, or is it the simplified engineering equations such as Chezy’s or Manning’s and moment distribution method? Is Galerkin formulation a first-principle, or is it not? And what does it mean by the knowledge profiles of WK1 to WK4? PO2 alone, if to be properly pondered, will shorten weeks of sleeping hours. And we have 12 POs all together.

3.0 THE 2ND DECADE

Then we came to the first half of the 2nd decade. Emphases were given on modern-active-student-centred-deep learning [2,3]. I could not agree more with the philosophy that learners must take charge of their learning. Feynman Learning Technique (FLT), to me, would be the best example of this. Feynman detailed the six steps of learning as follows:

1. Know what you want to learn
2. Read about it
3. Explain about it loudly as if you are explaining to somebody (if you are not with somebody)
4. In your explanation, identify which parts you felt uncomfortable with
5. Read that part again (which you felt uncomfortable)
6. Repeat/iterate the process until you are comfortable explaining all the points

But, for a student to practice this technique (my additional points):

1. He or she must first be curious about the subject as curiosity what usually makes one learn willingly. The challenge to us teacher is how to develop this curiosity amongst students.
2. Give them space and time to read, think (about the readings), explain it loudly, and come back to their reading. Reading and thinking are somehow still key. The challenge (to teachers) is to provide this conducive learning environment when we also expect them to deliver assignments, projects, tests, lab works and exams.

Based on these, I think the best approach to active learning is to combine flipped classroom and FLT. The former allows ample time in the classroom for discussions (thus, students can loudly speak of and debate about their readings and the videos they watched).

Will there be a trade-off? For this, I will say yes if we keep giving bad connotation to lecturing and reading. We can insist on enhancing the teachers' lecturing skills, for example, the lecturer's ability to reason, relate, make the pattern obvious, stress more on WHYs and induce curiosity. But to associate the act of lecturing as traditional, teacher-centred and even dull, I do not see the need. It would do more harms than goods.

And I am not so sure about the way many perceive the concept of student-centred; I refer to those extreme ones. My question is, how many worker-centred companies or industries, out there? Will the bosses assign task according to the personal situation and preference of an individual worker? At the same time, we are talking about producing engineers who are resilient, robust and able to adapt to the everchanging world. Is not there a contradiction somewhere?

Actually, in the 2nd decade, there was a sort of movement to modernise civil engineering courses. Newer contents were encouraged to be included (or emphasised), among others:

i. Health and safety [4]
ii. Built environment [5,6]
    - Sustainability
    - Green technologies and global warming
iii. Building information modelling (BIM) [7]
iv. Stochastic and optimization [8,9]
    - AI (ANN, Fuzzy, Genetic Algorithm)
    - Big Data
    - Internet of things (IoT)
v. Industrial revolution 4.0 (IR 4.0) [10]

4.0 WERE THERE TRADE-OFFS?

All these are good, but was there any trade-off? Up to this point, after 20 years, and the fact that the domain is still constrained by 24/7 “boundary condition”, I cannot help but suspect there was. At least, with the attention given to the newer elements, we might have overlooked the attention needed for the fundamental of engineering itself; its emphasis, delivery, and development. To cope with the newer elements and absorb as well as benefit from the exponential growth of knowledge, future engineers must have enhanced intellectual skills and capabilities, referred to as the higher level of thinking. And this when the concept of life-long learning comes into the picture.

We need to produce a civil engineer that can read reports from mechanical and electrical engineers, vice versa. It is not only about reading them but also understanding them deep so that all the parties can contribute effectively and in an accumulative manner. These attributes fall under the theme of being multi-disciplinary and effective team member. But what is the commonality? What are the starting point and the language that all the engineers speak? To answer, I share a couple of statements from the American Society of Civil Engineers (ASCE) [11,12]:

As the boundaries of technological knowledge expand, as new disciplines emerge, and as the boundaries between existing disciplines blur, professional civil engineers must increasingly draw upon a broad understanding of math and science fundamentals. Breadth in math and science provides a strong foundation for engineering problem-solving (Outcome 5) and lifelong learning (Outcome 9) [11].

Relative to today's approach, tomorrow's civil engineer—prior to entry into the practice of civil engineering at the professional level—will:

- master more mathematics, natural sciences, and engineering science fundamentals
- maintain technical breadth
- acquire broader exposure to the humanities and social sciences
- gain additional professional practice breadth
- achieve greater technical depth—that is, specialization [12].

Based on the ASCE statements above, we can say that all engineers' commonality, be it Civil, Mechanical, Electrical, Chemical, etc., is the mathematics and natural sciences (physics, chemistry) and their fundamentals. All engineers speak the same language at these levels.

Still talking about what we might have missed in the last decade, below is the table taken from a survey done by Johnson and May (2008) [13] funded by the Ove Arup Foundation and presented at the Institution of Structural Engineers (IStructE), UK. The table shows the different rank of importance given to structural analysis subjects by the academics and the industry people. While the paper highlighted the high agreement between the two parties, we can see how the industry highly perceives the theory of elasticity and the finite element method, higher than how academics perceive them.

Table 1: Rank of importance of structural analysis subjects [13]

Table 1: Importance of analysis capabilities for 'structural understanding' (0-5 high)

Academic		Industry	
Hand determinate	5.00	Hand determinate	5.00
Buckling	4.50	Theory of Elasticity	4.63
Plastic analysis	4.33	Buckling	4.45
Hand indeterminate	4.04	Plastic analysis	4.18
Torsion	3.90	Hand indeterminate	3.90
Theory of Elasticity	3.73	Torsion	3.80
Dynamics	3.50	Finite Elements	3.52
Plates & Shells	3.32	Dynamics	3.32
Matrix analysis	3.13	Matrix analysis	3.18
Finite Elements	3.00	Plates & Shells	3.00

When I conducted a curriculum benchmark study for my previous institution, I noticed that somewhere in 2014, the Civil Engineering programme at Imperial College London has revamped its syllabus. More emphases on the theory of elasticity, the partial differential equations and the Matlab programming (to complement the study of the formers). I am not sure whether this was a response to Johnson and May's report, but we can check. But have we responded too?

5.0 COMMONALITY IS KEY

I am disclosing my vision for 21st century CVE education in the next section. But the core of the idea is commonality. Therefore, to prepare the scene, I need to establish the concept of commonality in the way I understand and experienced it. I guess the best way to do this is by sharing some of my personal learning experiences.

I start by sharing how I first worked with artificial neural network (although I did not progress far except for a couple of publications). I first read Lofti Zadeh's book on Fuzzy Logic only to realize I need to dig deeper. My journey made me realize that it all boils down to the extremization of the objective functions. But this is similar to the variational approach of FEM, e.g. stationary principle of potential energy, Hamilton principle. The extremization act is the same; set the first derivative of the objective functions (of the former) or the functionals (of the latter) to zero; Walla, you will end up with a matrix system. Of course, the former's constraints can be treated similarly to the latter's boundary conditions or compatibility. I firmly believe this is how civil engineering students should learn AI, Big Data, IoT etc. They should learn it from the existing framework of civil engineering. No new framework is needed. The commonality between deterministic and stochastic analyses is at this level.

If not for my computational mechanics study (e.g. elasticity and fluid dynamics), I will forever think that Manning's flow rate equation and Euler-Bernoulli's beam equation are two unrelated equations. I will never realize that Stokes' flow equation, without the convection term (thus linear and steady), precisely resembles the structure's static condition. And the inclusion of the advective acceleration would invoke the unsteady flow (Navier-Stokes) in a similar manner a structure becomes dynamic. The reason being both need to satisfy the conservation law of momentum (Newton's 2nd Law). And I will never realize Re, Fr, Pe, are numbers of the ratio between the RHS and LHS of the various forms of Newton's 2nd Law. The commonality of solid and fluid mechanics (in its various forms) is at the Navier-Stokes level. The former is the reduced case of the latter.

Suppose I stick to solving the differential equation's homogenous part to obtain a beam's buckling loads and natural frequencies and to Mohr's Circle to determine the principal stresses. In that case, (although I can relate the first two together), I will never realize these three analyses are one under the Eigenvalue problems. I can use the same computer code to solve all three, almost without any modification! The commonality is obvious.

The commonality is key. It makes learning new knowledge feel like a mere extension, not an entirely new process that is laborious and fragmented. It allows the bird-eye view of everything. It enables a higher absorption rate to new knowledge as now the brain has become highly systematic and scientific. To me, this should be the brain structure of the future engineers.

But what makes all these possible now? What makes it possible to emphasise the computational mechanics over classical in the 21st-century CVE syllabus? Why has this not been done in the 90s? The answer is also the reason we are having this discussion in the first place. It is the knowledge and technology explosions that have changed the landscape of engineering, hence engineering education.

I firmly believe the reason for the fragmentation or specialization in the 20th century of mathematicians, physicists, chemists, engineers, you name it, was because mathematics and physics/mechanics were too difficult to handle. As buildings needed to be taller, cars to get faster and submarines to submerge deeper, the governing equations became highly coupled, of higher orders, highly nonlinear and sensitive. We knew early in the century that the matrix system could handle all these, but the computer to do the calculation was still at the embryonic stage. We were looking at a matrix size of hundreds of thousands (if not millions). Hence, while waiting (for the fully developed computer), the scientific communities chartered their path (of course, there were interactions). Engineers relied heavily on empirical data or the solutions from their engineer-cum-mathematician fellows in the forms of end-formulae, curves, and tables. I still remember the story told by my PhD supervisor, Professor David Nethercot, how, in the early 70s, he needed to punch his finite difference codes on cards and waited for weeks only to realize he did something wrong with the code. He studied structural stability, by the way.

All these are bygones now. With the user-friendly higher-level language programming like Matlab, Maple, Mathematica became highly available towards the end of the 1st decade of the 21st century, any don can do the maths. They are so simple (relative to C, Java or even Fortran), it is almost like using a scientific calculator. If this is not the present scene, it should be because this is the 3rd decade of the 21st century already; we should have flying cars by now.

Equipped with this calculator-like programming, engineering students have the tools to go down and look directly at the partial differential equations to understand the structural, fluid and soil behaviour. This is the deepest understanding one can have. So simple, they can build up the matrix system within days (if not hours) and play around with it to study different effects. This way, our students can have stronger fundamental understanding than us. This programming experience is also the prerequisite for them to use software like ANSYS, ABAQUS, ORION, HECs, etc. We keep hearing rubbish-in-rubbish-out, aren't we? With all that available at their disposal (which were not available during our times), if they are not better learners than us, there is something wrong with the system; there is something wrong with us teachers. This should be the logic.

Another reason why it should be a different playing field for them is the internet. There are thousands of videos on engineering programming, computational mechanics, vectors and tensors, computer software. We can watch the complete lecture by Bathe on FEM as the videos are now available on YouTube from MIT Open Course Ware. There are books and papers everywhere. There are forums where engineering students discuss and exchange source-codes with their counterparts all over the world. I know all these because these are the sources of learning for my final year, Masters and PhD students.

So, there you go, I have given my answers on why I believe it is possible now (hence a must) and was not in the 90s.One might argue that all these work for my students because they were at the postgraduate or undergrad dissertation levels. Not really. I am sure you are all well aware of the situation in Malaysia. Our forte is doing design (for lack of better words). When I received my students, they had almost zero background in programming and computational mechanics, just like when I started my PhD. But I have devised a system for them where it revolves around the concept of commonality, resembling what I have discussed at length above. I even wrote two books on FEM designed to compensate for the missing years of their undergraduate when it comes to these topics. The idea behind the books is, for every type of element, from the most straightforward bar structure to Navier-Stokes, I start by deriving the differential equations, deriving the shape functions, discretise the equations into a matrix system and code them in Matlab, repeat, for every single element. The idea is, I want them to see the pattern, to see the commonality that it involves the same argument and process, and the difference is nothing but an expansion. I do not opt for the principle of virtual works, but I go with Galerkin instead because the former is not general enough beyond structural modelling. The latter, since it operates directly on the differential equations, works for all. This is how I uphold the commonality. And I had a lot from my students about how they wished they were taught this way during their undergraduate study.

Now that I have set the scene, I am going to reveal my vision for civil engineering 21st century education.

6.0 CVE EDUCATION IN THE 21ST CENTURY: HOW IT SHOULD BE DESIGNED

The learning process of Civil Engineering in the 21st century should be designed in such a way that the attainment of new knowledge is just an extension of the existing ones. I believe that selecting the method of delivery that has the highest commonality can achieve this. In engineering, computational mechanics offer the highest commonality covering both solid and fluid. It was a difficult subject in the last century, but it should no longer be the case with the availability of calculator-like programming and all the sources on the internet.

With learning branches out from commonality, a learner can learn more contents, learn it quickly and understand it deeply. This is how a civil engineering student can venture into new territories like AI, Big Data, IR 4.0, sustainability, green technologies etc. A future civil engineering student should solve the global warming issue based on an energy functional extremized into a matrix system. Not just by suggesting planting more trees. With the Genetic Algorithm (GA), a future civil engineering student can develop the fully optimized construction plan of the lightest, cheapest, highest, quickest, but safest building. Such an endeavour has fallen into the realm of stochastic analysis, which is impossible to be carried out by the deterministic approach of engineering. But to develop such a capability, an engineer must go through the deterministic process first before he or she can get into the realm of stochastic engineering design. We always hear the saying of thinking outside the box. But before one can do that, he or she must first know the box's existence and wherein that box he or she is, then where outside is.

The way I envisage the education system is summarized in Figure 1. As can be seen, the fundamentals are established from the computational mechanics' framework complemented by computer programming. The governing equations (e.g. differential or integral equations, functionals) are discussed in both computational and fundamentals segments. There are two fundamentals to be established; deterministic and stochastic, of course with different magnitude of emphasis (highlighted by the bigger and bold fonts of the former) since we are civil engineering after all. We can introduce the optimisation concept for the stochastic fundamentals, say, by discussing how to determine the shortest route of public transport based on the Brachistochrone variational approach, a topic falls under civil engineering transportation.

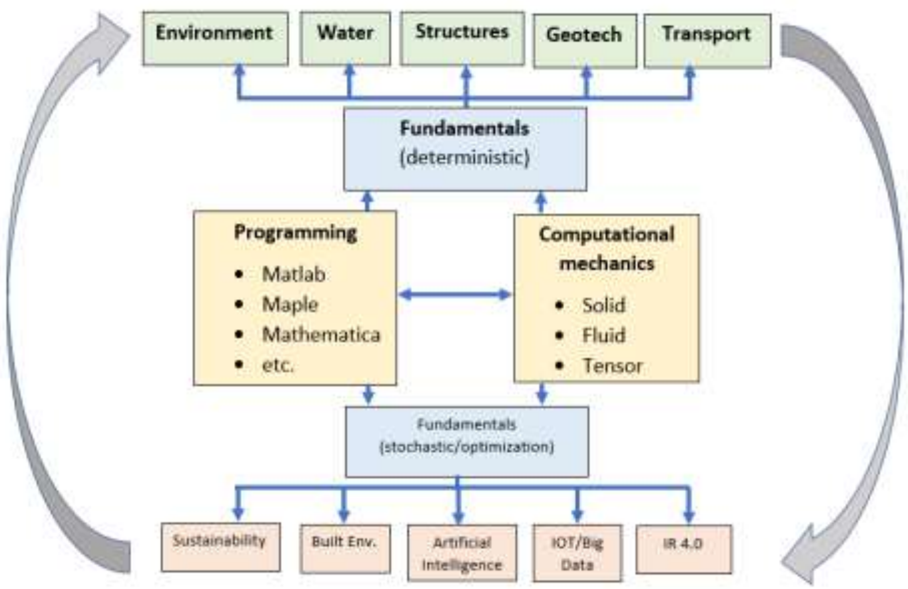

Figure 1: CVE 21st century education model

Civil engineering subdisciplines (e.g. structure, water, geotechnics, transportation, and environmental engineering) must branch out from the fundamentals in an extended and integrated manner. The newer elements (e.g. sustainability, built environment, AI, IOT etc.), if to be interjected, must be in the framework of engineering, that is, through the fundamentals of stochastic or optimization.

Once both domains have been established, the interaction will start to occur, represented by the two arrows. The stochastic knowledge will optimize the engineering design, while the engineering knowledge will expand the stochastic subdomains' horizon.

Will there be trade-offs? Indeed, there will be because we are constrained by the 24/7 "boundary condition". But we will make the trade-offs systematically and consciously. The principle remains, whatever we abandon, it must not sacrifice any engineering fundamentals but to enhance it. It still must be all from the first principles. We might need to abandon many classical approaches and replace them with the computational mechanics' framework. That is on the deterministic side. On the stochastic side, we need to insist that the interjection must suit the engineering framework and not just at the surface level. We need to avoid a neither-here-nor-there situation.

This is how we can produce future civil engineers who are holistic, multidisciplinary, resilient, adaptable to what may come and most important, life-long learners. In short, the higher-level thinking future engineers.

7.0 CLOSING REMARKS

There you go, the thoughts I gathered for years. Do I believe in the system I have proposed? Yes, I genuinely do. Do I think people will buy it? To this, I am not sure. It might sound too big and unrealistic. But I still hope Malaysian academia to consider it, if not in its entirety, in its essence. Perhaps, instead of revamping the current system, we can create a new civil engineering degree bracketed by computational mechanics (e.g. Meng (Civil-Comp. Mech.). But I genuinely believe 21st-century civil engineering education needs a new framework based on commonality offered by computational mechanics complemented by engineering programming. And learning new knowledge must be felt like extending the existing ones.

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