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An Enhanced Engineering Design Process incorporating Computational Thinking: A Conceptual Framework for Engineering Education

C.A.N. Johnson[1,2], M.F. Bin Daud[3], M. Bin Arsat[4] and W.N. Wan Hussin[3]

[1]Centre for Engineering Education, Universiti Teknologi Malaysia, Malaysia
[2]Dept of Marine Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
[3]School of Mechanical Engineering, Universiti Teknologi Malaysia, Malaysia.
[4]School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, Malaysia

Abstract

The engineer by training uses the engineering design process (EDP), which is a systematic and iterative problem-solving strategy to obtain desired solutions. Another problem-solving approach is computational thinking (CT) which by its emergence is open for all to deploy. Meanwhile, engineering problems are getting more complex and posing greater challenges to the fast-growing industrial world and society. Therefore, to mitigate these challenges, new strategies are constantly in demand. One of such strategies would be the introduction of an enhanced engineering design process (E-EDP), a combination of the traditional EDP and CT. The researchers undertook a qualitative study exploring the perceptions of engineering educators on how the integration of CT and EDP would form an enhanced engineering design process in this era. The outcome of the combination is as follows: problem definition, abstraction, logical/ algorithmic thinking, modelling, testing/ simulation, evaluation, communication, and design revision/ redesigning. E-EDP presents some notable advantages like deterministic results, efficiency, replicable solutions, and well-defined stages over the individual strategies. It offers contributions to engineering students, engineering institutions of learning, and industry.

Keywords: computational thinking, conceptual framework, engineering design process, enhanced engineering design process.

1 Introduction

The field of engineering has always provided solutions to the enormous challenges in society, and as these problems are resolved, new challenges are birthed. Problem-solving is essential to engineering with continuous improvement or innovations to meet the demands. As a contribution, therefore, engineering programmes are established to produce graduates in engineering for real-world problems which might not have been thought of beforehand, open-ended, complex in nature, and ill-defined [1], [2].

The engineer by training is open to a fundamental tool called the engineering design process (EDP), which is a systematic problem-solving strategy, iterative in nature, that follows a series of steps to get to the desired solution [3]. Because of its repetitive nature, part(s) of the process could recur several times before arriving at an optimised and best result. There are several variants of EDP being used today depending on the engineering discipline, type of projects, and other factors. In this study, the 8-step version of EDP has been adopted [4] and these are as follows: defining the problem; conducting research; brainstorming ideas; choosing the best solution; building a model; testing and evaluating a prototype; communicating the design to others; and finally, redesigning the solution.

Another problem-solving strategy for the 21st century called computational thinking (CT) has emerged for all to deploy. According to Wing and her collaborators, CT is the "thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively executable by an information-processing agent" [5], [6]. She added further that CT intersects with other forms of thinking like logical thinking and systems thinking [7]. The most important and high-level thought process in computational thinking is the abstraction process [8]. Apart from the abstraction process, others are decomposition, algorithmic logic, evaluation, pattern recognition, and generalisation. CT can be adapted by other professionals to fit the purpose in computational terms [8].

Engineering problems are getting more complex and challenging in our present world. Therefore, it has become imperative that to mitigate these challenges, new strategies are constantly in demand to be formulated and deployed. One of such strategies would be the introduction of an enhanced engineering design process (E-EDP), which is a combination of the traditional EDP and CT. The research question guiding this study is "Can EDP be improved upon for effective problem-solving according to the perception of some engineering educators"?

2 Methods

To explore the perception of some engineering educators on how EDP could be enhanced in the era of IR 4.0, a qualitative inquiry was conducted. The enhanced EDP would be the possible outcome of two problem-solving strategies namely CT and the traditional EDP. Denzin and Lincoln [9] define qualitative research as “a situated activity that locates the observer in the world which consists of a set of interpretive, material practices that make the world perceptible”. Leavy establishes that researchers use this approach to explore; to robustly investigate and learn about the social phenomenon; to unpack the meanings people ascribe to activities, situations, events, or artifacts; or build a depth of understanding about some dimension of social life [10].

The samples were drawn from two engineering institutions. the one located in the Southern part of Malaysia and the other in Southern Nigeria. A total of sixteen engineering educators were selected from the four main engineering disciplines namely chemical, civil, electrical, and mechanical using the purposive sampling technique.

In this study, data collection methods included document analysis, in-depth interviews, and observations as prescribed by Miles and his colleagues [11]. Document analysis [12], being a form of qualitative research technique was used for collecting data for computational thinking principles and practices as well as EDP in the journal articles and grey materials. Among the several variants of EDP, the one used by the National Research Council [4] for their work titled “Engineering in K-12 Education: Understanding the Status and Improving the Prospects” was adapted for this study. In furtherance of the process, an open-ended, in-depth interview was conducted with the participants. This is to elicit their perception of how EDP could be enhanced. Some observations were noted and recorded.

The collected data were sorted, coded, and analysed using the analytical hierarchical process (AHP) [13], an online decision-making tool, and NVIVO Version 12. AHP was used to choose the most relevant elements of CT for the study. The AHP is a decision analysis method that considers both qualitative and quantitative information. The use of the AHP approach provided by Saaty [14] was to assess the criteria weightings in a phenomenon. The NVIVO was used to analyse the perception of the engineering educators concerning the enhancement of EDP.

3 Results

The following results emerged after analysing the qualitative data gathered through exploring the perception of the engineering educators on how the EDP could be enhanced for effective problem-solving.

The key elements of CT were derived through the AHP analysis as indicated below in Fig.1 following the question “which criterion with respect to AHP priorities is more important, and how much more on a scale 1 to 9?” [13]:

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Thought Process	19.2%	1
2	Abstraction	12.9%	2
3	Algorithmic logic	10.7%	3
4	Decomposition	10.0%	4
5	Evaluation	8.7%	5
6	Generalization	8.7%	6
7	Analysis	4.9%	7
8	Modeling	3.1%	8
9	Simulation	3.1%	9
10	Automation	2.9%	10

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5	6	7	8	9	10
1	1	3.00	3.00	3.00	3.00	3.00	4.00	5.00	5.00	5.00
2	0.33	1	1.00	1.00	1.00	1.00	3.00	5.00	5.00	7.00
3	0.33	1.00	1	1.00	1.00	1.00	2.00	4.00	4.00	4.00
4	0.33	1.00	1.00	1	1.00	1.00	3.00	3.00	3.00	3.00
5	0.33	1.00	1.00	1.00	1	1.00	2.00	3.00	3.00	3.00
6	0.33	1.00	1.00	1.00	1.00	1	2.00	2.00	3.00	3.00
7	0.25	0.33	0.50	0.33	0.50	0.50	1	1.00	1.00	1.00
8	0.20	0.20	0.25	0.33	0.33	0.50	1.00	1	1.00	1.00
9	0.20	0.20	0.25	0.33	0.33	0.33	1.00	1.00	1	1.00
10	0.20	0.14	0.25	0.33	0.33	0.33	1.00	1.00	1.00	1

Number of comparisons = 136
Consistency Ratio CR = 2.0%

Principal eigen value = 17.509
Eigenvector solution: 4 iterations, delta = 2.8E-8

Fig 1 Selection of the elements of CT using AHP

From Fig. 1, abstraction, algorithmic logic, decomposition, evaluation, and pattern generalization were chosen as the main elements for the study.

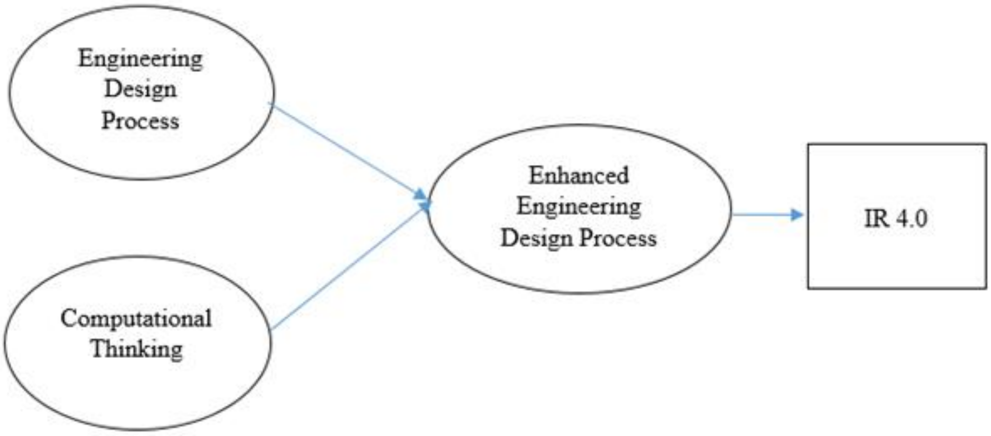

Fig 2. Integration of the CT and EDP to form the Enhanced Engineering Design Process

For the purposes of IR 4.0, an integration of CT and EDP to form the E-EDP would improve problem-solving capabilities and processes, and this was also backed up with results arising from the analysis of the perceptions of the engineering educators. Figure 2 shows this integration.

The key stages that emerged to form the E-EDP are displayed in Fig 3 on the next page which are problem definition, abstraction, logical/algorithmic thinking, modeling, testing/simulation, evaluation, communication, and design revision/redesigning. The advantages of E-EDP over CT and EDP are deterministic results, efficiency, replicable solutions, well-defined stages, etc.

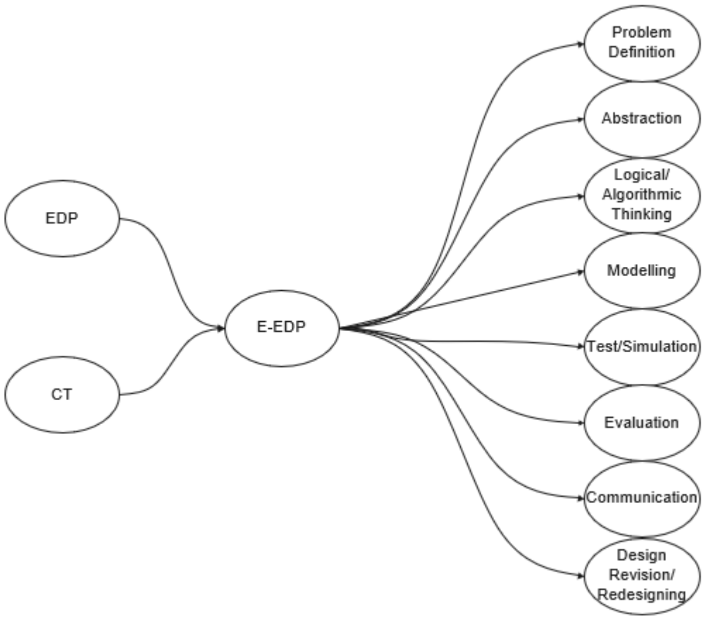

Fig 3 Mapping of the E-EDP

Operational definitions of the key stages of E-EDP:

a. Problem definition: At this stage, it is a process that involves brainstorming about a problem and researching the problem in other to attain the specific attributes of the problem which may be strongly connected to the problem or attribute that has no significant input into the problem.
b. Logical/Algorithmic thinking: This involves using logic to conceive an ideal solution and generating computable steps to the solution that is void of human interpretation, intuition, or judgment.
c. Modeling: This entails generating a model, or prototype using the generated computable steps, the model can be in any computable form such as mathematical.
d. Test/Simulation: This involves testing or simulating the generated models using specific properties of the problem.
e. Evaluation: This involves validating the results from the simulation or test models for performances or requirements.
f. Communication: This is used as feedback or discussion medium based on the problem and the provided solution.
g. Design Revision/Redesign: At this stage, there may be a need for an upgrade or maintenance, this calls for upgrading or redesigning the solution.

4 Conclusions and Contributions

The study brings to the fore the contributions of the conceptual framework to the engineering students by the educators and administrators affecting industry and society. The study put into consideration the perceptions of engineering educators on how the integration of CT and EDP would form an enhanced engineering design process in this era of technological advancement. The E-EDP utilizes parts of EDP and CT, hence enabling it to be used in cross-disciplinary fields. The solutions produced by E-EDP would be replicable and optimal and open to enhancement and modification. The flexibility of E-EDP makes it reliable for any size of the team, the stage precision makes it easier for anyone to use. Moreover, E-EDP emphasises more on logical thinking, algorithmic thinking, and abstraction, making it the ideal choice for engineers.

In view of the above, when this conceptual framework is implemented, it is expected to fulfill the following benefits to the engineering students, tertiary engineering institutions of learning, and the industry:

a. Engineering Students: It will provide the opportunity for the engineering students to build capacity on various core knowledge domains relating to the framework for handling challenging situations in themselves, in learning, and in industry. Subtly, it aids motivation and grit in the students for better academic performance and practice in the industry.
b. Engineering institutions of Learning: The framework promises to enrich the engineering curriculum through the introduction and integration of the main attributes of this framework devoid of the traditional ways of learning. The implementation of the revised curriculum puts the engineering educators in a great role to act as mentors with the support of the administrators who would provide strategic direction.
c. Industry: The industry would be taking in an already prepared crop of employees who are fit for purpose. This saves the industry time for capacity building with its attendant financial implications.

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