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Effectiveness of Computational Thinking in Problem Based Learning

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***Abstract*—National Education Policy 2020 demands the education system to acclimate problem based and discovery oriented learning. A problem used as a tool for teaching and learning can help to achieve the learning outcomes and also enhance cognitive and critical thinking skills. Self-directed learning is one of the essential skills needed for the today's working professionals. Problem based learning and computational Thinking methodologies have been used in varying contexts to achieve the desired course outcomes. This paper proposes a model to solve and analyze case studies using both the approaches. The model was tested using open book exams as assessment method for system design problems and computational thinking was found to be effective when combined with the problem based learning methodology. The instruments were validated using cronbach's alpha co-efficient and even the student feedback has been positive for the process. The model was analyzed using the case study research method. The results appear to be promising and can be used for most computer science courses which are algorithmic or problem solving in nature. Combining computational thinking with problem solving can be an effective way of course delivery and open book exams can be an effective assessment method.**

***Keywords*—Computational Thinking; Problem Based Learning; System Design; Open Book Exams**

***JEET Category*—Research**

I. INTRODUCTION

EDUCATION research has evolved from classical learning theories and principles to their applications (Pashler et al., 2008) on emerging new theories to meet the learning needs of Generation-Z students. Growing amidst the technology and being tech savvy, the present-day kids have their own learning needs being characterized by their schooling and upbringing (Seemiller & Grace, 2017). The methods and their pedagogy being segregated by the demography, root from the fundamental principles each finding its variant tied with academic needs and obligations. Education pedagogies have evolved according to the state-of-art needs from teaching methods to evaluation strategies. Blended learning styles have had their influence on various practices merged with numerous learning approaches (Akkoyunlu & Soylu, 2008). All the learning methods and improvements have been centered to develop the problem solving skills through various tools and techniques.

While there are many definitions defined in the literature based on the domain and context, in generalized terms, a 'problem' is an unwanted scenario. A problem is a situation that needs to be addressed. A problem is solved because it needs to be. A problem can be ignored if it has no significant effect on the system. A problem can be studied further to understand the implication of it on the system. Literature presents several dimensions that a problem can be looked from. Usually in a program curriculum students are saturated with vast amount of information and they are usually excited working with real time problems and scenarios (Barrows, 1996). A problem can be used as a tool for learning (Nickles, 1981). The problems complexity, formation, abstraction, structure, etc. defines the nature of the problem and type of the problem.

One of the methods that keeps problem as a center piece of learning is Problem Based Learning (PBL). The need for developing the reasoning skills or problem-solving process skills led to the foundations of PBL method (Barrows, 1984). The written and oral exams were not effective strategies to evaluate the clinical skills that a student had to develop through the degree which has history taking to diagnosis and management (Barrows & Abrahamson, 1964). PBL is not one method. It did not originate out of blue, all of a sudden. It was a combination of several validated principles meeting intended objectives. The idea was to start the learning process by beginning with a problem and learning by discovery. The idea was to pull out 'problem-boxes', sort of canned patient (Barrows & Mitchell, 1975).

PBL since its inception has been adapted with standpoints based on the demographic and environmental constraints. The method has been experimented and explored in several education and business domains as the research presents it to be an effective strategy for teaching and learning. One spectrum of the PBL is about designing effective strategies to use problems into pedagogy and another is designing evaluation methods for the designed strategy. This paper explores the usage of computational thinking and problem

solving for system design problems. The focus of the research is to evaluate the method effectiveness using open book exams. The primary motivation for this research is to support the National Education Policy 2020 which aims to build a knowledge base using problem based and discovery oriented learning approaches.

The paper is further divided into following sections. Section 2 presents the literature review on the related areas. Section 3 presents the method design and deliberations. Section 4 presents the results and data analysis. Section 5 presents the discussion and section 6 concludes the paper.

II. Literature Survey

Considering the stat-of-art and research focus, this section discusses the literature survey on problem based learning, computational thinking, open book exams and system design problems. The focus of the study is from computer science domain.

The 'problem,' being the central idea in problem-based learning, has been designed, delivered, and assessed from course level to university level. Problem taxonomy has been presented from ill-structured to structured, categorizing the problem classes and their properties and those appropriate to be used for PBL methods (Jonassen, 2011). Motivation, problem-solving skills, using knowledge to solve the problems and self-directed learning being the core components in PBL have been analyzed with literature supporting the evidence of improvement using PBL (Norman et.al., 1992). The effect on creative and critical thinking skills through PBL have been studied (Birgili, 2015). PBL have been used to enhance and advance the educational outcomes of collaborative, student-centered learning (Gwee, 2009). PBL have been challenged with the evaluation and assessment strategies to meet the overall objectives (Waters et al., 1997). Experiments have been carried out to evaluate the effect of scaffolding on student performance in problem based learning (Simons et al., 2007). PBL and traditional methods have been compared for effectiveness (Strobel et al., 2009).

Computational thinking is defined using four constituents namely abstraction, decomposition, pattern recognition, and algorithms (Wing, 2006). A research survey on the aspects of computational thinking concludes the need for more concrete definition of terminologies involved with the process (Selby &Woollard, 2013). Several aspects on how computational thinking is interconnected to problem solving have been studied. Experiments have been carried out to evaluate the effectiveness of PBL and computational thinking in programming domain (Chen, 2017). When problem based learning integrated with computer science, its effects and attitudes have been discussed (Kwon et al., 2021). A discussion of relationship between computational thinking and computer science has been deliberated. Several aspects on how computational thinking is interconnected to problem solving have been studied over the period of time. Even high school students have been trained on aspects of computational thinking as it's the need of the hour.

PBL is also defined by its evaluation methods as a written exam might not be an effective way of assessment. Experiments have been carried out to examine if open book exams have impact on student learning. A comparative analysis has been made in the practices for open and close book exams (Green, 2016). Assessments were carried out to inspect the long term retention practicing open book exams (Agarwal et al., 2008). Generating data tests for open book exams have been discussed and evaluated (Mihaylov, 2018). Experiments have been carried out to measure role of open book exams in PBL models (Heijne-Penninga et al., 2013).

System design has been an area in computer science where several core companies are using for hiring process. A study on understanding of system analysis with design by producing substantial description of projects has been carried out (Dennis, 2008). The focus on the principles mixed up with system analysis and design have been studied. The challenges relating to the system designed have been diagnosed (Martin, 2018). A study on practical approach towards learning objectives, skills and techniques linked to system analysis and design have been carried out (Valacich & George, 2022). An illustration to walk through actual design interview questions in addition to framework used to solve any system design problem have been studied (Alex, 2020).

As problem based learning, computational thinking, and system design focuses largely on complex problem solving, there is a need for an integrated method that can bring the best of three areas. The literature survey analysis provides the motivation to frame the research question and validate the methods using open book exams being an ideal method for evaluation.

III. Model and Methodology

This section presents the research question and process of its design through component graph, background and the model design. We use the case study research method as it best fits the current context of study.

A. Case Study Research Method

Case study research recently has found prominence in large proportions in psychology, history, education, and medicine and other fundamental sciences (Starman, 2013). A case study is usually defined by individual cases and not by the methods of inquiry used (Stake, 1994). Stake also identifies three types of case studies and for our approach we use collective approach among intrinsic, instrumental and collective methods. In collective approach numbers of cases studies are jointly studied to understand a phenomenon, population or general condition. For the evaluation of the current study, four case studies were designed.

B. Component Graph

Considering the literature survey, the key components of each of the modules were identified and connected through a graph. Figure 1 represents the graph. The indirectly connected components are joined through dotted lines. The case study research methodology was selected as it connects to the components we have already identified. All these components

form the epistemology for this research work leading to a design and assessment method.

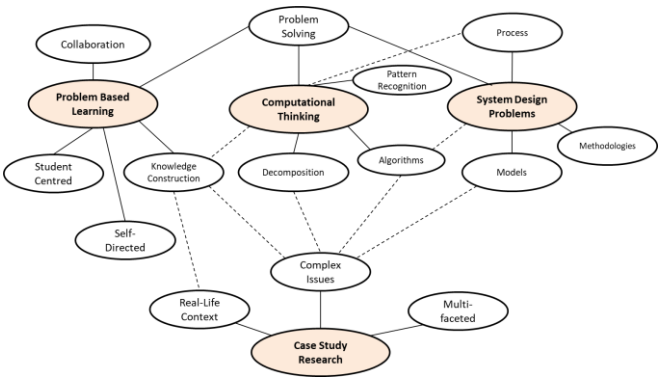

Fig. 1: Connecting components graph

Based on the graph and the components, a research question for the study was formulated.

C. Research Question

The research question aims to measure the effectiveness of using computational thinking with problem-based learning for system design problems. The question addresses the following concerns:

- Addressing system design problems with problem solving
- Addressing system design problems with problem based learning and computational thinking
- Their effect on self-directed learning

D. Model Design

The model designed can be seen in Figure 2 below. The teaching and learning components include sessions where case studies are discussed using PBL methods (Barrows, 1984) and using PBL and computational thinking methods (Wing, 2006). The model builds with simpler case studies to system design problems (Tilley, 2019). The assessments are open book exams tested for system design problems. The model can be employed to all the courses that emphasize on problem solving or are algorithmic in nature. The model can be easily employed to most computer science courses. The detailed discussion of the model is presented in the results and discussion section.

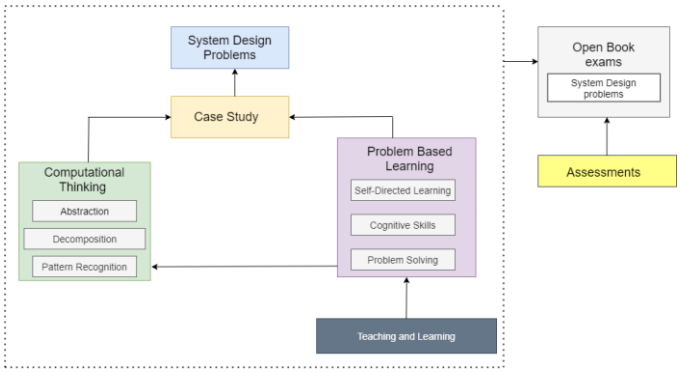

Fig. 2: PBL – CT Model

IV. Results and Data Analysis

The model was applied on a course offered jointly by Knit Space Software Research and Services Private Limited and KLE Technological University. The course was designed with a focus and objective to enhance problem solving and understand and infer models. The course was open to all interested students of computer science and engineering who had completed their two years of degree program. The course was designed for three credits where there was 25 contact hours and 25 take home works. In take home hours students had to complete five exams where each was evaluated for 20 marks. This section will majorly focus on assessment method used.

A. Course Delivery

The 25 contact hours of classes on model thinking, problem solving and computational thinking was delivered by Knit Space industry team. The course objectives are listed in Table I.

TABLE I
Course Objectives

Objective ID	Objective
Obj-1	To enhance problem solving skills
Obj-2	To understand the real time implication of models
Obj-3	To think in terms of models and infer rules and behaviors
Obj-4	To better understand system and data to improve decision making skills

The course delivery was through case studies. More than 20 case studies were designed from structured to ill-structured for the course delivery. All the sessions employed problem solving methods and no slides or presentations were used for the delivery. A problem and discussion followed by its inferences was the delivery model. Computational thinking sessions were also delivered using several case studies.

B. Structure of Exam

The course had five open exams and one of them was exclusively designed for system design problems. Four problems were designed where two of them had to solve using problem solving method and two of them using problem solving and computational thinking. Each question was provided with sub-questions to trigger the thinking process and answer presentation. The questions were selected from a list of top ten interview questions used by core hiring companies. The list of questions can be seen in Table II. The exam was open for five days.

TABLE II
Exam Questions

Question	Domain
Question 1	Design of a crawler
Question 2	Design of a message board service
Question 3	Design of a ride sharing service
Question 4	Design of an OTT platform

C. Sample Questions

Two sample questions are presented in this sub section one from problem solving and one from problem solving and computational thinking.

Question 1: Discuss the design of a web crawler. Following are the questions to ponder on which will help you to structure your answer:

- Why is web crawler essential? Why are they helpful?
- What are the components of a web crawler? What algorithms can you use?
- What is the design challenges associated in implementing a crawler?
- What kind of systems needs a crawler?

Question 4: Design a new OTT platform. (Example: Netflix, Amazon Prime, etc.). Discuss the major components of this system and its operational design. Following are the guiding questions (and not limited to):

- How can you decompose this system?
- What patterns do you observe in this system?
- What are the abstractions? Can you model them for larger application?
- What are the major components and algorithms that you can use to build this application?

As we can see, question 2 explicitly asked to use the computational thinking model to solve the problem while in question 1, though it was not explicitly stated, it was open for interpretations.

D. Analysis of Design Problems

Using the case study research method, the system design questions were analyzed to identify the major modules and 5 components were identified as presented in Figure 3.

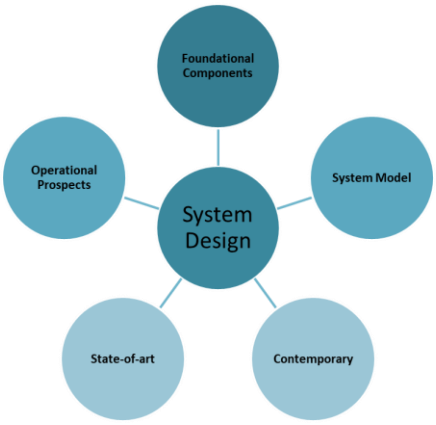

Fig. 3: System Design Components

All the system design problems (around ten as identified in culture) were analyzed to build a template on answer expectations. The points that an answer must cover were segregated to five categories. An ideal answer had to cover all or most and is expected by the engineering graduates. The five identified categories are Foundational Components, System Model, Contemporary, State-of-art, and Operational Aspects. All the five along with their sub components are presented in Table III.

TABLE III
ANSWER CATEGORIES

Category	Keyword
Foundational Components	Why (K1) System features (K2) System specific features (K3) Design aspects (K4)
System Model	Architecture (K5) Components (K6) Analysis of different components (K7) Protocols (K8) Algorithms (K9)
Contemporary	Improvements (K10) Relating concepts (K11) Future scope (K12)
State-of-art	Applications (K13) Alternatives (K14) Other domain applications (K15)
Operational prospects	Depth-ness in takeaways (K16) Stakeholders (K17) Design challenges (K18)

E. Scores and Analysis

A total of 33 students had registered for the course and 24 students made submissions for the considered assessment. 9 students submitted answers for all the 4 questions and remaining all others had missed at least one. The analysis is carried out on 9 students only as they had submitted all the four. All other submissions are not considered for analysis and hence a random sampling. The scoring for question 4 can be seen in Table IV below. The keywords K are as identified in Table III.

TABLE IV
SCORING FOR QUESTION 4

K	S1	S2	S3	S4	S5	S6	S7	S8	S9
K1	1	1	1	1	0	0	0	0	1
K2	1	1	0	1	0	1	1	1	1
K3	1	1	1	1	0	0	1	0	1
K4	1	0	1	1	1	1	1	1	1
K5	0	1	0	0	0	0	0	0	1
K6	1	1	1	0	1	1	1	1	1
K7	1	1	1	0	1	1	1	1	1
K8	1	0	0	0	0	0	0	0	1
K9	0	1	1	0	1	1	0	1	1
K18	1	1	1	1	0	0	1	1	0
K10	1	1	1	0	1	1	1	1	1
K11	0	0	0	0	0	0	0	0	0
K12	0	0	0	0	0	0	0	0	0
K13	0	0	1	1	0	0	0	1	1
K14	0	0	0	0	0	0	0	0	0
K15	0	1	1	0	0	0	0	1	0
K16	2	2	1	2	2	2	2	2	0
K17	0	0	1	1	1	1	0	0	1

A value 1 means that the parameter was described in the answer and 0 indicates otherwise. S1 to S9 indicate the 9

students. The score for each question was 5 marks, adding up to a total of 20 marks. Answers submitted were graded on the points as mentioned in Table III. If the answer covered the point, like described a score of 1 was allotted otherwise 0. As a qualitative method (case study research method) is employed for study analysis, 9 still forms to be a good number for the study. The takeaway (analysis) and depth point carried two points. The scores were then normalized to five points. The average scores of each question can be seen in Figure 4 below.

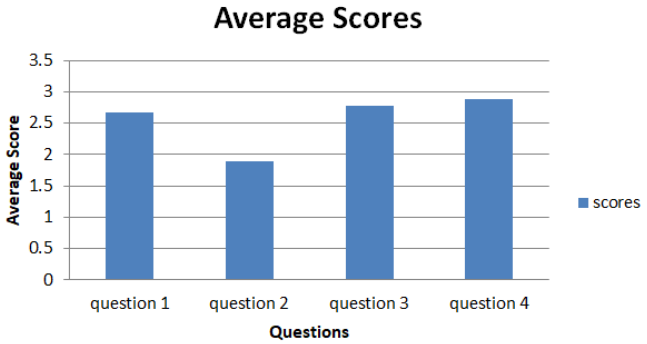

Fig. 4: Average score of each question

If we look at the average scores, the average of Question 3 and 4 are more as compared to Question 1 and 2. The total scores and statistics can be seen in Table V.

TABLE V
SCORING OF QUESTION 4

Question	Average Score	Variance
Question 1	2.67	0.25
Question 2	1.89	0.36
Question 3	2.78	0.19
Question 4	2.89	0.11

The graph of total scores of each student and the mean (linear) can be seen in Figure 5 below. The total exam score was 20 and the mean score was 10.22 marks.

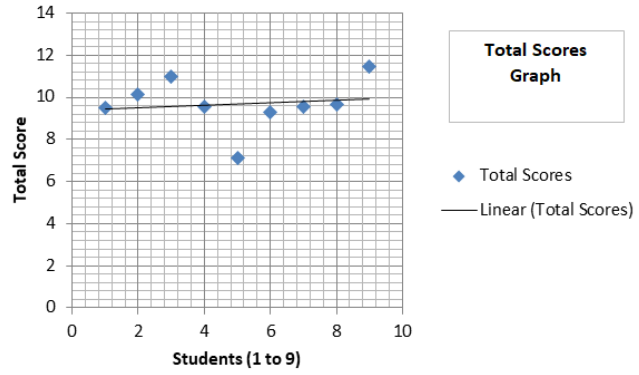

Fig. 5: Total scores graph

F. Instrument Validation

The instrument designed was validated using cronbach's alpha co-efficient (Tavakol & Dennick, 2011). The coefficient that tests the internal consistency is used as the data operated was on interval scale. The formula can be seen in Equation 1.

$$\rho_T = \frac{k^2\overline{\sigma_{ij}}}{\sigma^2_X} \quad (1)$$

Here ρ_T is the tau-equivalent reliability and k is the number of items, σ_{ij} is the covariance between X_i and X_j and σ^2_X is item variances and inter-item covariance. For the data and scores, the co-efficient turned out to be 0.8. The score of 0.8 indicates a 'good' internal consistency and hence validates the instrument used for analysis.

G. Feedback

A course feedback was collected from the students who underwent the course after their consent. 28 students completed the feedback form. Likert scale was used for the feedback where the students had to rate on the scale of 1 to 5 where 1 being highly ineffective and 5 being highly effective. For the question rate on the effectiveness of the course with respect to the new skills/perspectives you have developed, the results can be seen in Figure 6 below.

The question asked was to rate on the effectiveness of the course with respect to the new skills/perspectives that they had developed. The x-axis indicates the rating and y-axis presents the number of students.

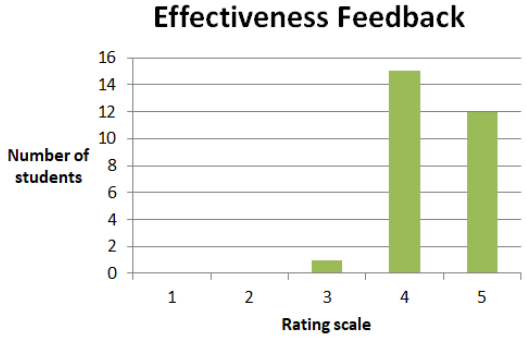

Fig. 6: Feedback on delivery effectiveness

More than 95% students agreed that the method was effective (who rated 4 or 5).

V. DISCUSSION

The average scores indicate that the computational thinking promotes self-directed learning effectively by giving the right trigger questions to ponder over. State-of-art and Operational prospects were covered in depth and in detail when problems were solved using computational thinking framework. Students attempted the first two questions by applying problem solving and next two questions by computational thinking. It was observed that students where they applied computational thinking performed better than problem solving based on the parameters-analysis of different components, depth-ness in takeaways, stakeholders and design aspects.

The average word count and number of figures drawn for each answer were analyzed and is presented in Table VI.

TABLE VI
WORD COUNT ANALYSIS

Question Set	Average Word Count	Total Figures
Question 1 and 2	666	7
Question 3 and 4	678	7

We can notice that the average word counts and total figures included in answers is almost the same for both problems with problem solving and problem solving with computational thinking. With higher average score for question 3 and 4 is an indication that the qualities of answers were better within the same word limit. Every question included writing a take-away from the answer and it was used to measure the analysis depth. Computational thinking questions scored more marks here proving that it makes a student to justify and analyze better than the traditional problem solving process.

The National Education Policy 2020 (Aithal & Aithal, 2020) insists to build a knowledge base that can be used for teaching and learning. For the discovery oriented learning and for the self-directed learning, the discussed process can be a framework for all the courses that have a system perspective or algorithmic in nature.

VI. CONCLUSION

PBL is a research-proven effective way to develop self-directed learning skills. Based on the nature of the course, the method can be adapted at different levels. A model devised to validate the problem based learning and fusion with computational thinking was found to be effective when assessed with open book exams. The model can be used for the courses that are problem oriented or algorithmic in nature. The future scope of this work involves building a generic framework that can be adapted to other courses and with different forms of assessments.

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