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Integrating Design Thinking and Computational Thinking in Engineering Education A Technology-Supported Pedagogical Model

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***Abstract* - The growing sophistication of the engineering problems and the accelerated digitalization of the professional practice are the reason why the pedagogical models must incorporate both creative and analytical learning as well as the one that is technology-enabled. In this paper, the authors explore a technology-driven pedagogical framework that combines Design Thinking and Computational Thinking to improve the development of both integrated learning/problem solving abilities in engineering education. The quantitative, cross-sectional research design was used, in which 267 engineering students were surveyed by using a structured questionnaire. To test the relationship between Design Thinking and Computational Thinking with Technology Support, Integrated Learning, and Problem-Solving Skills, the empirical study method was utilized as the Partial Least Squares Structural Equation Modeling (PLS-SEM). The results show that Design Thinking, Computational Thinking, and Technology Support have substantial and positive impacts on Integrated Learning, which shows that they complement each other in the process of enabling holistic learning experiences. The high and considerable impact of Integrated Learning on the Problem-Solving Skills of the students proves that it is a core issue of the given learning mechanism in the proposed scheme of things. The model has an acceptable power of explanation, and it is reflective of the predictive relevance of combining creative and computational pedagogies in learning environments that are technologically enhanced. The current research is relevant to the literature of engineering education because it offers empirical results to support a holistic pedagogical model to balance both human-focused innovation and computational rigor. The results have practical implications in terms of educators, curriculum developers, and policymakers who can create technology empowered and future-ready engineering curricula to facilitate deeper learning and competent problem solving abilities.**

***Index Terms*— Design Thinking, Computational Thinking, Technology Supported Learning, Integrated Learning, Problem Solving Skills**

I. INTRODUCTION

The paradigmatic shift in engineering education has been further catalyzed by the swiftness of technology, complicated nature of problems and change of expectation of both industry and society. In digitally mediated settings, contemporary engineers must not only show technical competency, but also show higher-order thinking and cognitive skills, such as creativity, systems-thinking, flexibility, and problem-solving abilities. Nevertheless, the traditional or traditional forms of engineering pedagogies, which are mainly content based and test based, have been increasingly criticized to be inadequate as far as instilling these competencies is concerned. It is this mismatch between educational activity and professional requirements which has provoked the quest to find pedagogical paradigms that unite human-centered innovation with computational discipline.

In this regard, Design Thinking has come to the fore as a pedagogic practice that puts empathy, ideation, experimentation and journey iterations of solutions at the forefront. Its problem-oriented and learner-centered orientation is consistent with the requirement to solve complex, unsolvable, and socially embedded engineering problems. According to previous research, Design Thinking can help increase creativity, teamwork, and awareness of users among students of engineering. However, applied alone, Design Thinking might fail to produce adequate structured analytical argument and algorithmic problem breaking-skills, and these skills become more and more important in data-driven and technology-intensive engineering fields.

In the opposite, Computational Thinking has become a foundational cognitive framework of engineering and STEM education that includes abstraction, decomposition, algorithmic thinking, and solving logical problems. Computational Thinking provides learners with methodical methods of addressing complicated issues and developing solutions that can be scaled and be efficient. Although increasingly gaining significance, Computational Thinking is frequently limited to programming-focused or otherwise technically insulated learning environments, limiting its ability to facilitate holistic problem and real-world problem understanding when it is not learned within the broader context of human-centered and experiential learning models.

More recent pedagogical research suggests that Design Thinking and Computational Thinking can be used jointly to create a complementary and synergistic mode of learning. Design Thinking brings in creativity, empathy, and exploration, whereas Computational Thinking brings in structure, precision and depth of analysis. This combination strategy can be used to improve student engagement, foster more meaningful learning, and build problem-solving skills that are transferable when integrated into a technology-mediated learning environment involving the use of digital collaboration tools, simulation platforms, and interactive learning technologies. Nevertheless, though such integrated pedagogical models have strong conceptual justifications, empirical evidence that attests such models is limited, especially in engineering educational settings.

The current body of empirical research tends to focus on Design Thinking or Computational Thinking separately, providing few interactions on the impacts of the two on learning processes and outcomes. Further, the facilitation of the integration of these cognitive frameworks by technology support has not been given enough attention on empirical discrepancies. As a result, the gap in the knowledge of the impact of a technology-based implementation of the Design Thinking and the Computational Thinking on the integrated learning and problem-solving abilities of engineering students is still too big.

II. REVIEW OF LITERATURE

The Design Thinking focuses on problem identification, ideation, experimentation, and refinement through empathy and all these concepts serve to promote holistic and experiential learning[2]. In the engineering learning process, these activities help the learners to relate theory and practice, hence making it easier to integrate innovative and critical thinking[13]. According to previous research, Design Thinking-oriented pedagogy will help students improve their skills at bringing multidisciplinary knowledge together and be able to meaningfully interact with the situation of complex problems. In this regard, Design Thinking will have a major role in enhancing integrated learning outcomes[1].

H1: Design Thinking is a positive and important process in improving the integrated learning among the engineering students.

Computational Thinking also provides students with systematic thinking skills like abstraction, decomposition, and algorithmic thinking, which are necessary in the analysis and solution of complex engineering problems[6]. These abilities help to organize knowledge systematically and think logically, and as such, supplements creative exploration. The capacity of students to combine the rigor of analysis together with the conceptual meaning is enhanced in case of the inclusion of Computational Thinking in larger learning exercises[15]. Accordingly, it can be expected that Computational Thinking will be a key factor in supporting integrated learning in the engineering learning process[11].

H2: Computational Thinking is an important and beneficial factor towards improving integrated learning in engineering students.

Technology based learning environments offer the necessary infrastructure that will facilitate collaborative learning, simulations, visualization and experimentation through repetition. Design Thinking and Computational Thinking can be practically implemented in such environments because they provide the platform to prototype, model, and analyze data[4]. According to previous studies, technology support increases the involvement of learners and promotes the process of integrating various mental processes. Consequently, the integrative learning will heavily rely on technology support to enable it[8].

H3: Technology support is a positive and significant factor that can promote integrated learning among students of engineering[3].

Integrated learning shows the capacity of students to combine creative, analytical, and technological information into integrated strategies of solving problems[9]. In engineering learning, this synthesis holds great importance towards solving complex, ill structured problems, which need both innovation and methodical reasoning. The empirical data indicates that the integrated learning processes are the most effective in enhancing the problem-solving abilities of the students by facilitating the deeper knowledge and transferability of the skills. Integrated learning will therefore be a key element towards improving problem solving skills[5].

H4: The integrated learning is a positive and significant factor that improves problem-solving skills among engineering students.

Integrated learning is a major concept that is being exposed in the literature as one of the most important ways in which pedagogical interventions can help in shaping the learning outcomes[10]. The Design Thinking, Computational Thinking, and technology support are used mainly as inputs in the teaching process, whereas the problem-solving skills are a higher level learning outcome[12]. The cognitive and pedagogical tool, which converts these inputs into meaningful outputs, is integrated learning. Therefore, it is conceptually justified to assume that integrated learning intermediates the linkages between pedagogical drivers and problem-solving skills[14].

H5: Design Thinking and problem-solving skills have a relationship between Design Thinking and problem-solving skills mediated by integrated learning between engineering students.

H6: there is a relationship between the ability of Computational Thinking and problem-solving among engineering students mediated by Integrated Learning.

H7: Technology support is mediated by integrated learning to problem-solving skills of engineering students.

III. RESEARCH METHODOLOGY

This paper will be quantitative and cross-sectional research design to determine the effectiveness of introducing Design Thinking and Computational Thinking into a technology-based pedagogical framework used in engineering education. The quantitative method is suitable since the research is supposed to test hypothesized association among latent measures and evaluate the predictive power of the hypothesized framework. A sample of 267 engineering

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students in undergraduate and postgraduate programs were used to gather the data through a purposive sampling method to expose the respondents to technology-facilitated and problem-based learning conditions. The size of the sample meets the minimum stipulations of the Partial Least Squares Structural Equation Modeling (PLS-SEM)[7]. The primary data was collected with the help of a structured questionnaire with a five-point Likert scale. This measurement tool consisted of reflective scale items of Design Thinking, Computational Thinking, Technology Support, Integrated Learning, and Problem-Solving Skills. The suggested research framework places Design Thinking, Computational Thinking, and Technology Support as exogenous concepts that can have an impact on the Integrated Learning and subsequently on Problem-Solving Skills. The analysis of the data was performed with the help of SmartPLS in two steps. Indicator loadings, composite reliability, average variance extracted, and HTMT ratios were used to test the measurement model with the parameter of reliability and validity. Path coefficients, coefficient of determination (R^2), effect size, and bootstrapping (5, 000 subsamples) were used to evaluate the structural model to determine the significance of the hypothesized relationships.

Figure I. SmartPLS Output

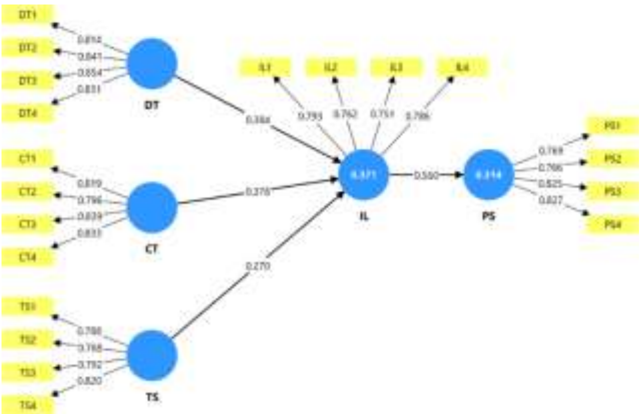

Figure I shows the SmartPLS structural model that indicates the hypothesized relationship between Design Thinking (DT), Computational Thinking (CT), Technology Support (TS), Integrated Learning (IL), and Problem-Solving Skills (PS). The visual representation indicates that DT, CT and TS are exogenous constructs that predict Integrated Learning and Integrated Learning is an important endogenous construct that predicts Problem-Solving Skills. The standardized path coefficients presented in the model show the strength and the direction of each relationship, which proves the conceptual hypothesis that combined contributions of integrated pedagogical and technological inputs lead to increased learning outcomes. The mediation position of Integrated Learning is supported by the model structure in the translation of pedagogical methods to effective problem-solving skills.

TABLE I. R^2 TABLE

	R-square	R-square adjusted
IL	0.371	0.363
PS	0.314	0.311

Table I shows the values of R-Sq and adjusted R-Sq of the endogenous variables, which are Integrated Learning and Problem-Solving Skills. Integrated Learning has the R2 value of 0.371, which implies that Design Thinking, Computational Thinking, and Technology Support have the effect of illuminating 37.1 percent of the variance in Integrated Learning. Equally, Problem-Solving Skills exhibit R^2 0.314, implying that, the Integrated Learning is the driver of the variance attributed to the problem-solving skills of the students by 31.4%. These are moderate explaining values, which is good and significant in educational and behavioral studies, and validates the predictive implication of the suggested model.

TABLE II. F SQUARE

	CT	DT	IL	PS	TS
CT			0.228		
DT			0.234		
IL				0.457	
PS					
TS			0.115		

Table II shows the f-square values of the individual effect of exogenous constructs on the endogenous variables. The effect sizes of Design Thinking ($f^2 = 0.234$) and Computational Thinking ($f^2 = 0.228$) on Integrated Learning are rather medium, which means that they have a significant impact on pedagogy. Technology Support demonstrates a less significant although significant effect size ($f^2 = 0.115$) on Integrated Learning, which shows that it enables it. Problem-Solving Skills: The effect size of Integrated Learning is high ($f^2 = 0.457$), which shows that it is a key learning process that leads to problem-solving.

TABLE III CONSTRUCT RELIABILITY AND VALIDITY

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
CT	0.841	0.850	0.893	0.675
DT	0.856	0.862	0.902	0.698

IL	0.776	0.777	0.856	0.598
PS	0.810	0.821	0.875	0.636
TS	0.803	0.810	0.871	0.628

Table III contains the overview of the reliability and convergent validation statistics of all the constructs. The values of Cronbach alpha and composite reliability of all the constructs are higher than the desired 0.70 hence internal consistency. The values of AVE are over or near the acceptable value of 0.50 which shows that there is sufficient convergent validity. These findings affirm that the measurement model is sound and that the indicators are able to measure their respective latent constructs.

TABLE IV DISCRIMINANT VALIDITY

	CT	**DT**	**IL**	**PS**	**TS**
CT					
DT	0.060				
IL	0.456	0.483			
PS	0.333	0.361	0.696		
TS	0.068	0.075	0.354	0.276	

Table IV displays the results of the discriminant validity on the FornellLarcker criterion. Discriminant validity is satisfactory as the square roots of AVE of each construct are higher than their inter-construct correlations. This proves that the different constructs are empirically different and they are measuring different conceptual domains, which confirms the strength of the measurement model.

TABLE V MODEL FIT

	Saturated model	**Estimated model**
SRMR	0.058	0.062
d_ULS	0.710	0.813
d_G	0.232	0.238
Chi-square	373.672	380.557
NFI	0.829	0.825

Table V shows the model fit indices of the saturated and the estimated models. The values of SRMR (0.058 and 0.062) are less than the suggested figure which is 0.08 and the model fits well. The values of the NFI are near the acceptable range, which also contributes to the sufficiency of the model. Taken together, these indices indicate that the suggested structural model is portrayed by a reasonable overall fit.

TABLE VI PATH COEFFICIENT

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
CT -> IL	0.378	0.382	0.047	8.046	0.000
DT -> IL	0.384	0.386	0.046	8.396	0.000
IL -> PS	0.560	0.564	0.038	14.607	0.000
TS -> IL	0.270	0.273	0.052	5.215	0.000

Table VI gives the structural path coefficients, t-statistics and p-values. The findings reveal that Design Thinking (= 0.384), Computational Thinking (= 0.378), and Technology Support (= 0.270) are influential in a positive way on the Integrated Learning. In its turn, Problem-Solving Skills is greatly affected by ILS (r = 0.560). The statistic analysis of all the hypothesized relationships proved to be statistically significant at $p < 0.001$, which is the strong empirical evidence of the offered model.

VI. FINDINGS

The empirical evidence confirms the hypothesis of the technology-based pedagogical model that incorporates Design Thinking, Computational Thinking, and Technology Support in the engineering education. The findings suggest that Design Thinking and Computational Thinking have substantial and positive influence on Integrated Learning, and the effect sizes are rather similar and significant, which emphasizes the complementary pedagogical functions. Technology Support is also found to have statistically significant impact on Integrated Learning, showing the enabling role it plays in the process of cognitive integration. The Integrated Learning is a mechanism of learning that has a high and powerful impact on problem-solving skills. The predictive relevance of the framework is confirmed by the explanatory power of the model as shown by the values of R

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2 of Integrated Learning and Problem-Solving Skills. All in all, the results confirm the mediating effect of the Integrated Learning in converting pedagogical and technological inputs into higher problem-solving abilities in engineering students.

V. CONCLUSION

The research contributes to the field of engineering education research by empirically confirming a technology-based pedagogic model, which is a combination of Design Thinking and Computational Thinking. The findings prove the idea that neither creative nor analytical methods can be used alone, but it is necessary to combine them with the help of corresponding educational technologies to promote meaningful learning and competence in resolving problems. Placing Integrated Learning at the core of the learning process, the research not only makes its contribution to the theory of pedagogy but also gives the empirical evidence of the holistic and future-oriented approach to the engineering education. The results highlight the value of creating curricula that are balanced in terms of creativity and computational rigor, as well as technology-driven learning environments, to equip students with engineering challenges in the real world that are complex.

VI. MANAGERIAL IMPLICATION

The results have significant recommendations to academic leaders, curriculum designers, as well as educators. Design Thinking and Computational Thinking are to be incorporated into the curriculum of engineering institutions, not as independent parts of the instruction. Pedagogical strategies that incorporate human-oriented innovation and analytical thinking need to be the focus of faculty development programs, and assisted with the help of digital technologies like simulations, collaboration platforms, and prototyping technologies. The investments in the structure of technology in institutions of learning are essential because technology facilitation contributes greatly to the integrated learning procedures. These insights can also be used by policymakers and accreditation bodies to advance outcome-based education models based on the nature of learning, which focus on integrated learning and problem-solving skills according to the demands of the industry.

VII. LIMITATIONS OF THE STUDY

The study has limitations although it has made contributions. The cross-sectional research design limits the capacity to generalize on the basis of causal relationships with time. Self-reported measures were used to collect data, which is open to common method bias and subjectivity of respondents. Moreover, the sample was only restricted to engineering students at a particular level of education, which can have an impact on the generalization of the results in other disciplines or geographies.

VIII. FUTURE RESEARCH

The research studies of the future can be performed according to the longitudinal research or the experimental research design to study the long-term effect of the usage of the integrated pedagogical models on the learning outcomes. The moderating variables that researchers may study include learning styles, digital readiness or the quality of instructional design. Inter-disciplinary or inter-institutional comparative research would increase the generalizability of the model. Other studies can also explore how sophisticated technologies, including artificial intelligence-based learning analytics or virtual laboratories, can be useful to deepen the integration of Design Thinking and Computational Thinking and enhance their influence on professional skills.

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