

A Non-Parametric Analysis Of Engineering Competencies In Primary And Lower Secondary Students Via A Project-Based Learning Framework: A Case Study Of The Idektep Program

Phatcharee Toghaw Thongrattana^{1*}, Naruetep Suwantada², Prapaisri Sudasna Na Ayudthya³

¹ Faculty of Engineering, Kasetsart University, Bangkok, Thailand. Email: fengprt@ku.ac.th

² School of Digital Media and Cinematic Arts, Bangkok University, Bangkok, Thailand. Email: naruetep.su@bu.ac.th

³ Faculty of Engineering, Kasetsart University, Bangkok, Thailand. Email: fengpsa@ku.ac.th

* Corresponding Author: fengprt@ku.ac.th

Abstract: This study aims to develop engineering competencies in primary and lower secondary school students through project-based learning grounded in a competency-based education (CBE) framework. The instructional model emphasizes problem-solving, systems thinking, and hands-on learning. The iDektep initiative, a project under the Faculty of Engineering at Kasetsart University, was employed as a case study. Engineering skill development in children aged 7–15 is essential for preparing them for a technology-driven world, fostering creativity and innovative design thinking from an early age. The study identified eight core engineering competencies: systems thinking (SK01), creative thinking (SK02), design and user experience (SK03), analytical thinking (SK04), programming (SK05), technological literacy (SK06), leadership (SK07), and resilience (SK08). The competency development process showed statistically significant improvements in students' performance. Using the Mann–Whitney U test, no significant differences were found across gender in all eight competencies. When comparing students across five learning cohorts in the "Level 1: Fundamental Digital Robot" program, and across age groups (6–9, 10–12, and 13–15 years) by using The Kruskal–Wallis Test, results indicated that design and user experience (SK03) and programming (SK05) skills did not differ significantly at the 0.01 significance level. This suggests that the learning approach effectively enhances design and programming skills regardless of age group or cohort, and that both male and female students can successfully develop all eight competencies. However, further refinement of learning activities is recommended, particularly to strengthen analytical thinking and other underdeveloped skills.

Keywords: Engineering Competencies, Project-Based Learning, Competency-Based Learning, Robotics Education.

1. INTRODUCTION

In the context of rapid technological advancement and global socio-economic transformation, the early development of engineering and innovation skills has become increasingly vital. Preparing young learners with foundational competencies in engineering thinking, problem-solving, and creativity is essential for cultivating a future workforce capable of addressing emerging challenges [1], [2].

Project-Based Learning (PBL) is widely recognized as an effective pedagogical approach that fosters the acquisition of engineering competencies through hands-on experiences and real-world problem-solving. When integrated with Competency-Based Learning (CBL), PBL enhances students' ability to transfer knowledge into practical applications, supporting both cognitive and behavioral skill development [3], [4].

In Thailand, the adoption of STEM (Science, Technology, Engineering, and Mathematics) education at the primary level reflects a national effort to strengthen 21st-century skills, including analytical thinking, collaboration, and adaptability. Programs such as "iDektep," developed by the Faculty of Engineering at Kasetsart University, exemplify this integration. The initiative employs a combination of robotics, programming, artificial intelligence, and data analysis within a PBL-CBL framework to engage students in engineering-focused tasks [7], [8].

This strategic alignment with national education reform is further supported by institutions such as the Thailand Development Research Institute (TDRI), which highlights the importance of enhancing STEM readiness to meet future labor market demands in science and engineering domains [9]. Beyond skill

development, experiential learning also promotes self-efficacy, motivation, and the discovery of individual strengths—key elements contributing to long-term academic and professional success [10], [11].

This study proposes a learning model that integrates Project-Based Learning with Competency-Based Learning to examine its effects on engineering competency development among primary school students. By leveraging the context of the iDektep program, the research aims to provide empirical insights and a scalable framework that supports youth development in alignment with future technological and societal needs.

2. RESEARCH OBJECTIVES & HYPOTHESES

Research Objectives

This study aims to explore the integration of Project-Based Learning (PBL) and Competency-Based Learning (CBL) in fostering engineering competencies among primary school students. The specific objective of the research is as follows:

To examine the impact of project-based learning on the development of engineering competencies, with a focus on evaluating students' skills in problem-solving, creative thinking, and teamwork.

Research Hypotheses

The research is guided by the following hypotheses:

H1: The implementation of a competency-based project learning model will result in a statistically significant improvement in students' engineering competencies compared to traditional learning methods.

H2: Students participating in the iDektep project will demonstrate higher levels of engineering competencies after the intervention.

3. Literature Review

Competency-Based Learning (CBL)

Competency-Based Learning (CBL) is grounded in constructivist theory, which posits that learners actively construct knowledge through their own experiences [4]. In the context of engineering education, CBL is increasingly recognized as a critical approach, as the acquisition of engineering competence extends beyond rote memorization or standardized assessments. Instead, it emphasizes the application of skills and knowledge to real-world situations [5]. According to [6], CBL enhances key 21st-century competencies such as analytical thinking, problem-solving, and collaboration. Reference [3] further highlight the role of CBL in enabling learners to develop transferable skills that are essential in engineering and technology-driven environments.

Project-Based Learning (PBL)

Project-Based Learning (PBL) is an instructional methodology that supports both academic and socio-emotional skill development. Research by [12] and [14] indicates that PBL enhances students' capacity to engage with complex problems, particularly in STEM fields. Through active engagement in real-world tasks, learners develop deeper understanding, intrinsic motivation, and confidence in problem-solving. [13] emphasize that PBL effectively integrates STEM disciplines by engaging students in contextually relevant challenges. Furthermore, PBL fosters critical thinking, creativity, and teamwork, preparing students for dynamic, technology-driven futures [12].

Engineering Competencies

Engineering competencies refer to the ability to apply scientific, mathematical, and technological knowledge to solve practical problems. Key dimensions include complex problem-solving, design thinking, and collaborative work. Reference [15] stresses the importance of developing these competencies from an early age to prepare future professionals for increasingly complex technological challenges. Reference [4] demonstrates that engaging learners in authentic, hands-on problem-solving fosters analytical skills and practical reasoning. Reference [16] affirm that design thinking enables students to formulate and test engineering solutions creatively and iteratively. Moreover, collaborative problem-solving nurtures essential communication and teamwork abilities, which are foundational in engineering practice [6].

Table 1. Engineering competencies in this study categorized by type and description

Code	Skill	Skill Description	Skills Category [26]
SK.01	Systems Thinking	Ability to understand systems and relationships within a system, analyze causes and effects, and link information to find solutions. Inspired by Peter Senge's "The Fifth Discipline".	Cognitive skills
SK.02	Creative Thinking	The ability to generate new ideas and create unique innovations. Includes the ability to connect prior knowledge to generate new possibilities.	Cognitive skills
SK.03	Design and User Experience	The ability to design user-friendly systems that are accessible and provide a positive experience. Includes usability and accessibility.	Technology skills
SK.04	Analytical Thinking	The ability to process information in depth, extract core concepts, and evaluate data for sound conclusions. Helps identify patterns and make decisions.	Cognitive skills
SK.05	Programming	The ability to write code or give commands to robots/machines to achieve desired functions. Involves logical thinking and computational concepts.	Technology skills
SK.06	Technological Literacy	Understanding and applying technology appropriately. Includes digital tools, online platforms, and new innovations relevant to tasks.	Technology skills
SK.07	Leadership	The ability to take initiative, inspire others, and work collaboratively toward shared goals. Involves decision-making and responsibility.	Working with others
SK.08	Resilience	The ability to recover from failure, manage frustration, and adapt to change. Involves self-confidence and emotional regulation.	Self-efficacy

STEM Education and the Discovery of Personal Talents

STEM education in Thailand plays a critical role in equipping young learners with analytical, problem-solving, and engineering-related skills necessary for the 21st century. Integrating scientific, technological, and mathematical content into real-life problem-solving activities allows students to develop both technical competence and self-awareness of their individual strengths and interests [7]. Reference [27] and [10] argue that early exposure to hands-on STEM activities fosters intrinsic motivation and sustained engagement. Reference [9] underscores that aligning STEM with project-based approaches not only enhances skill development but also helps students discover their unique aptitudes and innovative potential.

The iDektep Program: A Case Study

The "iDektep" program, developed by the Faculty of Engineering at Kasetsart University, serves as a practical case study in applying PBL to develop engineering competencies among primary school students. The program emphasizes real-world challenges that incorporate robotics, artificial intelligence, and digital technologies. Through these activities, students enhance their problem-solving, design thinking, and collaborative skills [8]. In parallel, national initiatives such as the Little Scientists' House Thailand Project and Chevron Enjoy Science emphasize the value of project-based and STEM learning in early education. These programs demonstrate measurable improvements in children's scientific reasoning and engagement with technology [17], [18]. The collective findings from these initiatives support the integration of PBL and STEM as effective strategies for preparing children to navigate a technology-centric future.

4. RESEARCH METHODOLOGY

Literature Review and Preliminary Framework Development

The study began with a comprehensive review of relevant literature on the development of engineering competencies in primary education. The focus was placed on both national and international research addressing 21st-century skills such as systems thinking, creative thinking, analytical problem-solving, and technological literacy. Insights from the literature informed the design of a learning framework aimed at developing engineering competencies among primary school students, particularly within the context of the iDektep project, which utilizes project-based learning to foster technical and problem-solving skills.

Research Design

This study employed an experimental research design using a single-group posttest-only methodology. The sample consisted of two cohorts of primary school students enrolled in the Level 1 (LV1) program of the iDektep initiative, with 107 students in each cohort (total $n = 107$). The instructional plan was delivered over 10 sessions, with each session followed by a post-lesson evaluation to assess learning outcomes related to engineering competencies such as systems thinking, creativity, design, and engineering problem-solving.

The performance outcomes of the two cohorts were compared using statistical techniques to evaluate the consistency and effectiveness of the instructional approach.

Research Instruments

This study utilized two key research instruments:

1. Online Competency-Based Assessment System: This digital platform enabled instructors and coaches to assess students' learning behaviors and competencies during project-based activities. The platform

supported real-time data collection, tracking eight core competencies and storing data in a centralized database for subsequent analysis.

2. Non-parametric Statistical Tools: To compare student performance across multiple variables such as cohort, gender, and age, non-parametric methods were employed. Specifically, the Kruskal-Wallis Test was used to assess differences in competency scores across more than two independent ordinal-level groups, and the Mann-Whitney U Test was used for gender-based comparisons. This approach was selected due to the ordinal nature of the data and the non-normal distribution observed.

The Kruskal-Wallis H test is a non-parametric alternative to one-way ANOVA, appropriate for analyzing differences across three or more independent groups when data are ordinal, non-normally distributed, or sample sizes are unequal [19], [20]. Widely used in educational and behavioral research, the test is especially valuable in studies involving project-based or competency-based learning, where outcomes are often measured via rubrics or Likert scales. Reference [21] and [22] demonstrated its use in evaluating instructional differences across curricula and teacher preparation models.

In STEM and engineering education, it supports evaluation of interventions involving robotics, design thinking, and technology-enhanced learning [23]. Its ability to handle rank-based data makes it well-suited for early education contexts, where developmental variation and small samples challenge parametric methods.

Thus, the Kruskal-Wallis test is a statistically sound method for analyzing group differences in non-parametric educational data, supporting rigorous and inclusive analysis across diverse learning environments.

The Mann-Whitney U test is a non-parametric method suitable for comparing two independent groups when data are ordinal, non-normally distributed, or derived from small samples [20]. It is frequently used in competency-based education research to evaluate outcomes measured through rubric scores or Likert-type scales. In STEM and engineering education, this test has been applied to assess gender-based differences in competencies such as systems thinking, design, and programming. Studies by [24] and [22] found no statistically significant gender differences in creative or technical skills among students engaged in robotics and project-based learning, highlighting the effectiveness of inclusive instructional designs.

Overall, the Mann-Whitney U test is a robust tool for evaluating gender equity in engineering education, particularly under conditions where parametric assumptions are unmet. Its use ensures rigorous and fair analysis in competency-based evaluations.

These statistical analyses were used to test the hypotheses regarding the influence of demographic cohort and age variables on the engineering competency scores as shown in Table 2

Table 2 Summary of Statistical Tests Used for Group Comparisons by Demographic Factors

Factor	Number of Groups	Sample Sizes	Statistical Test
Gender	2 (Male, Female)	96, 11	Mann-Whitney U Test
Cohort	5 (Cohort 12,13,14,15,16)	29, 18, 13, 29,18	Kruskal Wallis Test
Age	3 (6-9, 10-12, 13-15 years old)	64, 27, 16	Kruskal Wallis Test

Data Collection Procedures

Data were collected after each instructional session using the online assessment platform. Evaluation criteria included learning behaviors, creative thinking, and problem-solving abilities. The system recorded the data in real-time and stored it for cumulative analysis to track skill development and learning progress.

5. RESULTS

Gender-Based Comparison of Engineering Competencies

To investigate potential gender-based differences in engineering competency development, The Mann-Whitney U test was applied using gender as the grouping variable. The analysis covered eight core competencies (SK01-SK08), with the results presented in Table 3.

Table 3. The Mann–Whitney U test Results for Gender-Based Differences in Competency Scores

Competency	W-Value	P-Value.
SK01: Systems Thinking	5104.00	0.415
SK02: Creative Thinking	5222.50	0.697
SK03: Design and User Experience	5225.00	0.678
SK04: Analytical Thinking	5163.00	0.833
SK05: Programming	5131.00	0.59
SK06: Technological Literacy	5227.50	0.659
SK07: Leadership	5156.00	0.778
SK08: Resilience	5133.50	0.608

All p-values exceeded the 5 percent significance level, indicating no statistically significant differences in competency scores between male and female students across all eight domains. These results suggest that the project-based, competency-driven learning model supported equitable development of engineering competencies regardless of gender.

This finding aligns with prior studies (e.g., [24] [25]), which report minimal gender disparity when students are given equal access to hands-on, inclusive learning environments.

Student Cohorts-Based Comparison of Engineering Competencies

To assess whether engineering competency development varied across cohorts, the Kruskal–Wallis H test was applied using cohort as the grouping variable. Eight core competencies (SK01–SK08) were analyzed. The test results are presented in Table 4.

Table 4. Kruskal–Wallis H Test Results for Engineering Competencies by Cohorts

Competency	Kruskal–Wallis H	df	Asymp. Sig.
SK01: Systems Thinking	23.368	4	0
SK02: Creative Thinking	13.757	4	0.008
SK03: Design and User Experience	10.819	4	0.029
SK04: Analytical Thinking	36.522	4	0
SK05: Programming	9.269	4	0.055
SK06: Technological Literacy	28.333	4	0
SK07: Leadership	20.029	4	0
SK08: Resilience	69.696	4	0

The analysis revealed statistically significant differences across cohorts in seven of the eight competencies ($p < 0.05$), including systems thinking (SK01), creative thinking (SK02), design and user experience (SK03), analytical thinking (SK04), technological literacy (SK06), leadership (SK07), and resilience (SK08). Programming (SK05) did not reach statistical significance ($p > 0.05$) and at significant 99 percent confident interval, the design and user experience (SK03) did reach statistical significance ($p > 0.01$), though the results suggest a possible trend warranting further exploration.

These findings indicate that the effectiveness of the project-based learning model varied across cohorts, potentially reflecting differences in instructional implementation, student composition, or contextual factors. Further analysis may help identify specific factors contributing to variability in competency outcomes.

Age-Based Comparison of Engineering Competencies

To examine whether age influenced engineering competency development, the Kruskal–Wallis H test was applied using age group as the independent variable. Students were divided into three age brackets. The results for all eight competencies are summarized in Table 5.

Table 5. Kruskal–Wallis H Test Results for Engineering Competencies by Age Group

Competency	Kruskal–Wallis H	df	Asymp. Sig.
SK01: Systems Thinking	25.3	2	0
SK02: Creative Thinking	9.474	2	0.009
SK03: Design and User Experience	1.899	2	0.387
SK04: Analytical Thinking	32.302	2	0
SK05: Programming	3.565	2	0.168
SK06: Technological Literacy	25.323	2	0
SK07: Leadership	15.497	2	0
SK08: Resilience	41.963	2	0

The analysis revealed statistically significant differences across age groups for seven out of eight competencies ($p < .05$), including systems thinking (SK01), creative thinking (SK02), analytical thinking (SK04), technological literacy (SK06), leadership (SK07), and resilience (SK08). No significant differences were observed for design (SK03) and programming (SK05), suggesting that these skills may develop similarly across age groups within the program context.

These findings indicate that age plays a notable role in the development of several core engineering competencies. The results underscore the importance of age-responsive instructional strategies, especially in domains requiring advanced systems reasoning, leadership, and adaptive thinking.

6. DISCUSSION

The findings of this study provide important insights into how engineering competencies develop among primary school students in a project-based, competency-driven learning environment. Three key comparative analyses were conducted—based on gender, cohort, and age group—to evaluate the effectiveness and equity of the instructional model.

Gender-Based Comparison

The Mann–Whitney U test revealed no statistically significant differences in any of the eight engineering competencies between male and female students. This result aligns with prior research (e.g., [24] [25]), which suggests that when provided with equitable access to hands-on and inclusive instructional environments, students of all genders can achieve comparable outcomes. The absence of significant gender-based disparities underscores the program's potential to promote inclusivity and reduce traditional gender gaps often observed in STEM education.

Cohort-Based Comparison

In contrast, the analysis across five student cohorts demonstrated statistically significant differences in seven of the eight measured competencies. These differences may reflect variations in instructional delivery, cohort-specific dynamics, or contextual factors such as facilitator expertise and group interaction. The only competency that did reach statistical significance was programming (SK05), though the p-value ($= 0.055$) indicates a potential trend worth further examination since p-value is pretty much closed to 0.05.

These cohort-based discrepancies emphasize the importance of consistency in implementation and instructional fidelity. While the project-based model has shown effectiveness, its impact may vary depending on execution and learner grouping. Monitoring these factors is essential for program scalability and continuous improvement.

Age-Based Comparison

The analysis across three age groups revealed statistically significant differences in competencies such as systems thinking, analytical thinking, technological literacy, leadership, and resilience. However, no significant differences were observed in design (SK03) and programming (SK05), suggesting that these skills may be more age-neutral within the instructional scope of the program.

These findings support the notion that cognitive maturity influences the acquisition of higher-order thinking skills, particularly in systems reasoning and adaptive capacities. Younger learners may require more scaffolded support in developing these competencies, whereas design and basic programming can be introduced more uniformly across age levels.

Summary of Implications

Overall, the results suggest that the competency-based project learning model offers a robust framework for developing engineering competencies in primary education. While gender equity is well supported, variations across cohorts and age groups point to the need for tailored instructional strategies and standardized program implementation.

Future work should investigate which specific pedagogical elements contribute to consistent competency development across diverse learner profiles. Additionally, longitudinal studies could explore how these competencies evolve over time and their influence on students' future STEM engagement.

7. CONCLUSION AND FUTURE WORK

This study investigated the development of engineering competencies in primary school students through a competency-based, project-driven learning model. The results demonstrate that such a model effectively cultivates a range of essential skills, including systems thinking, creative and analytical problem-solving, technological literacy, leadership, and resilience. Notably, gender did not significantly influence competency outcomes, indicating that the learning environment supports equity. However, differences observed across cohorts and age groups suggest that learner characteristics and instructional variability can affect the consistency of learning outcomes.

The findings support the use of project-based and competency-based approaches in early engineering education and highlight the importance of age-responsive and consistently implemented pedagogical strategies. These approaches are especially relevant for preparing young learners to navigate the demands of a technology-driven future.

Future research should focus on several key areas. First, longitudinal studies are needed to assess the long-term impact of competency development on learners' academic trajectories and career interests in STEM fields. Second, further investigation into instructional design elements that optimize learning across age groups and cohorts will be valuable. Finally, integrating emerging technologies such as AI-assisted feedback and adaptive learning platforms could further enhance personalization and learning efficiency in engineering education.

By addressing these areas, future work can contribute to a more scalable, inclusive, and impactful framework for developing the next generation of engineers and innovators.

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