ENHANCING STUDENTS' PERFORMANCE USING PROBLEM BASED LEARNING METHODS UNDER DIFFERENT PROGRAMS OF SELECT SCHOOL IN THAILAND

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ABSTRACT: *This study investigates how various Problem-Based Learning (PBL) approaches could be integrated into digital platforms to enhance science learning outcomes for Thai secondary school learners, aiming to enhance their critical and problem-solving skills. Traditional teaching techniques in Thailand usually place a strong emphasis on rote memorization, which limits pupils' capacity to engage in more sophisticated scientific reasoning. This study addresses the need for innovative, student-cantered teaching strategies that promote conceptual understanding and real-world application. Using a convergent mixed method design, 160 students from four programs at a Thai Government Secondary School took part. Data was collected by individual interviews, four performance tasks pertaining to the different types of PBL (explanation, fact-finding, strategy and moral dilemma), and a 30-item circulatory system pre- test and post-test. The numeric data was analyzed using ANOVA and descriptive statistics, and the qualitative data was examined using thematic analysis. According to the findings, it was revealed that digital PBL methods led to substantial improvements in students' science performance, with gains in explanatory and procedural knowledge. The low pre-test scores to high post-test scores, and differences across PBL methods indicated varied impacts on specific learning outcomes. Students reported higher engagement and deeper understanding when using strategy and explaining PBL tasks.*

According to the results of the study, digital PBL is a helpful tactic for enhancing scientific education in Thailand by promoting both conceptual understanding and practical skills. It calls for additional digital strategies that encourage critical thinking and moral reasoning problems suitable for many cultural settings.

Keywords: Digital PBL, Science Education, Critical thinking, Procedural knowledge, Explanatory learning, Mix-method research, Thai secondary students

1. INTRODUCTION

There are still many barriers to science education in Thailand, even with initiatives to update curriculum and instructional strategies. Thai students persistently underperform in science, reading and math, according to the Program for International Students Assessment (PISA) compared to global benchmarks. The average science score decreased from 426 in 2018 to 409 in 2022, falling short of the OECD average of 485. This redirects deeper issues in how science subjects are taught and learned in Thai classrooms [3].

Despite modern regulations that encourage active learning, traditional lecture-based teaching methods are still widely used, particularly in the provinces of Thailand. Students have fewer opportunities to practice and improve their higher order thinking skills. This traditional approach limits students' exposure to real-world scientific challenges that need creativity, critical thinking and teamwork [5, 12].

Problem-Based Learning (PBL) has gained popularity as a pedagogical approach to address these shortcomings. Collaborating with others, exploring open-ended problems, and applying their conceptual knowledge in real-world situations are all encouraged for students. PBL has been shown to increase motivation, foster deeper engagement with scientific content, and enhance academic performance [15]. When paired with digital platforms, which offer asynchronous learning opportunities, access to multimedia resources, and interactive simulation production capabilities, PBL becomes even more powerful [8, 44]

Although PBL has proven its benefits and potential, still this method is not widely utilized in Thai basic education. A lack of digital literacy, limited access to educational resources and poor teacher preparation are some of the problems that prevent its full implementation [14]. Previous research has extensively explored various dimensions of the teaching–learning process, including pedagogical strategies [15–20], student preferences and readiness [21, 22], student motivation and attitudes [23– 26], teachers' skills, competencies, and challenges [27– 29], and assessment techniques and tools [30–33], as well as other influencing factors [34–40], all aimed at improving student learning outcomes. However, limited scholarly attention has examined PBL's effects on basic and secondary education in Thailand [10, 46].

Therefore, it is crucial to look at how different problem-based learning methods such as explanation problems, fact-finding problems, strategy problems and moral dilemmas affect students' scientific learning results. The goal of the study is to assess the effectiveness of PBL among Matthayom students in the Northeastern region of Thailand when combined with digital learning platforms [7, 11, 46]. It is supported by constructivist and experiential learning theories and is based on Barrows' taxonomy.

This study examines the performances of students in the Education Hub, Mini English Program, Science Gifted and Thai Regular Program on pre-tests and post-tests.

Additionally, it looks at the extent to which digital PBL potentially enhances the explanatory, descriptive, procedural and personal knowledge. In order to improve academic performance and advance educational equity across Thailand's basic education system, the study aims to offer an effective method for integrating PBL into scientific and innovative education.

This study specifically sought to answer the following problems:

1. What is the pre-test and post-test performance of the students from:
1.1. Education Hub Program
1.2 Mini-English Program
1.3 Science Gifted Program
1.4 Thai-Regular Program
2. What is the student performance outcome as to their problem-based learning in terms of;
2.1. explanatory knowledge
2.2. descriptive knowledge
2.3. Procedural knowledge 2.4.personal knowledge?
3. Is there a significant difference in the students' problem-based learning outcomes when group according to the teaching method as to;
3.1. explanation problem;
3.2. fact-finding problem;
3.3. strategy problem;
3.4. moral dilemma?
4. What are the experiences of the learners in different programs on the use of PBL?

2. RESEARCH METHODOLOGY

This study employed a convergent mixed method design which includes gathering of both qualitative and quantitative data simultaneously followed by merging of the two data collected for comparison, validation and comprehensive interpretation.

Convergent mixed method design, which provides a comprehensive understanding of how different PBL approaches impact students' learning experiences and outcomes, is used in the study's analysis of both data. There are four types of problem-based learning strategies, according to Barrows, and they are all used in a digital platform that aims to enhance students' capacity for critical, problem-solving thought as well as the effectiveness of these strategies in improving their academic performance in science [2]. Four groups of forty students each from four different Thai programs are formed by the researcher-namely Education Hub, Mini- English, Science Gifted and Thai regular program. Participation was completely optional and had no impact on grades or academic status.

Data was collected and analyze after the researcher administers all the pretests, posttests, performance tasks and interviews regarding their experiences with digital PBL.

2.1. Participants

The research was conducted on Matthayom 2 students of Piyamaharachalai School, a Science-Government School situated in Northeastern region of Thailand, specifically in the Mekong River Basin (MRB) [12]. The school has four different programs namely: Education Hub, Mini- English, Science Gifted and Thai Regular Program. Every student-participant took part in a digital platform that offered discussion tools for the science topic in circulatory system. Convenience sampling was used to select students who are willing to participate and currently under the program. The 30-item test was based on the OBEC Thailand Curriculum.

2.2. Research Instrument

The study employed three main data collection tools; these were a teacher-made test, which were the pre-test and post-test, a performance task utilizing a rubric and semi-structured interview. The pre-test and post-test were developed to assess the academic performance of the students in science concepts related to the circulatory system. The performance task was used to assess the student's critical thinking and problem-solving skills related to the circulatory system. The different performance tasks were based on competencies of the OBEC Thailand Curriculum and centered on the four (4) PBL methods (explanation problems, fact-finding problems, strategy problems, and moral dilemmas). The performance task rubrics consist of indicators ranging from outstanding (8pts), going to proficient (6pts), to developing (4pts) and to beginning (2pts). Meanwhile, a semi-structured interview was used to assess the experiences of the student in terms of the utilization of the different PBL methods in the learning environment in science. The interview was about the overall satisfaction on the use of PBL methods, the usability of PBL in digital platforms and its impact on learning.

2.3. Data Gathering Procedure

A formal request letter was sent to the school director and research office of Piyamaharachalai School, Thailand to obtain permission before the conduct of the study. Thai and foreign teachers validated the research tools. Before implementation of the different PBL methods on digital learning. Pre-test were given to all students from different programs. All groups took the same tests and were given the same direction and time.

In the first stage, each program was assigned to a specific PBL method. EdHub students were centered on explanation problems, MEP students on fact-finding problems, SCG students on strategy problems and Thai-regular students on moral dilemmas. Problem-based learning (PBL) materials were given to the students through a digital platform (IQ Candy). This science portal website was not intended to replace the existing Thai books prescribed by OBEC. This digital learning material only comprises a lesson with problem-based learning worksheets, discussion and performance task and rubrics.

In the second stage, during the period of implementations of digital PBL, students underwent focus group and individual interviews during and after the implementation of the PBL methods to determine their experiences, challenges and perceptions towards the utilization of PBL methods on digital platforms in science subjects.

In the third stage, after facilitating learning through different PBL methods on a digital platform. Students had taken a post-test to assess their academic performance in science. Each program was then assigned series of performance tasks to complete using the designated PBL methods. Each program's performance outcomes were evaluated using a rubric that was validated by both Thai and foreign teachers.

2.4. Data Analysis

The statistical tools employed for the analysis of the pretest, posttest and surveys were created to effectively meet the research objectives. Normality testing was conducted to check assumptions for parametric tests.

This study used descriptive statistics such as mean, frequency, percentage and standard deviation to illustrate the students' pre-test and post-test performance across each program. Performance task was interpreted using verbal indicators such as outstanding (31-40), proficient
(21-30), developing (11-20) and beginning (0-10). One Way Analysis of Variance (ANOVA).

For Statement of the Problem 1, the pre-test and post-test scores of students in each program were measured to determine changes in academic performance following implementation of Problem-Based Learning (PBL) strategies. The mean was calculated for each set of scores to assess overall group performance before and after the intervention using a five-point scale (poor-excellent). For Statement of the Problem 2, the analysis for the performance utilized frequency, percentage, mean, and standard deviation metrics. The performance tasks of students were assessed in each domain, namely, explanatory, descriptive, procedural, and personal using a scale from beginning to outstanding. Meanwhile, for Statement of the Problem 3, to assess the impact of the problem-based learning (PBL) method on student outcomes, a One-Way Analysis of Variance (ANOVA) was performed. This test evaluated whether there were statistically significant performance differences among the four teaching methods. The hypotheses were tested at a significance level of 0.05. ANOVA helped identify which specific types of PBL were more effective in enhancing student performance achievement. Finally, for Statement of the Problem 4, the qualitative feedback gathered from student interviews were examined using thematic analysis with six step procedure which involves data understanding, coding, topic identification, reviewing of themes, defining themes and making reports. Open coding was used to identify recurring themes in student responses [14]. The categorization and grouping of similar ideas have produced four main themes that reflect the students' shared experiences and perspectives on the use of digital PBL. These evaluations provide insight into how students perceive problem-based learning (PBL) in their courses, highlighting its shortcomings, benefits, and areas for improvement.

3. RESULT AND DISCUSSION

3.1. Pre-Test and Post-Test Performance from EdHub, MEP, SCG and Thai-Regular Programs

Table 1. Pre-test and Post-test Scores, Learning Gains

Science Competency (SC)	Pre-test (M, SD)	Post-test (M, SD)	Learning Gain	Interpretation
SC 3.1 Function of the Circulatory System	1.73 (0.96)	2.43 (0.81)	0.70	Minimal improvement
SC 3.2 Blood Composition	1.79 (1.27)	5.07 (1.25)	3.28	Substantial improvement
SC 3.3 Blood Vessels	1.09 (0.87)	4.13 (0.95)	3.04	Substantial improvement
SC 3.4 Heart Anatomy	1.41 (0.87)	3.56 (0.65)	2.15	Notable improvement
SC 3.5 Blood Flow	2.12 (1.28)	6.84 (1.28)	4.72	Strong improvement
SC 3.6 Blood Pressure	0.61 (0.65)	1.73 (0.52)	1.12	Modest improvement
SC 3.7 Diseases Related to the Circulatory System	0.82 (0.82)	2.62 (0.62)	1.80	Modest improvement

Legend: < 1.00 – Minimal Improvement; 1.00–1.99 – Modest Improvement; 2.00–2.99 – Notable Improvement; 3.00–3.99 – Substantial Improvement; 4.00 and above – Strong Improvement.

The pre-test scores revealed a relatively low overall mean of 9.57 (SD = 3.13), suggesting that students had below- average prior knowledge or mastery of the content before the intervention. In contrast, the post-test scores yielded a substantially higher mean of 25.79 (SD = 2.96), indicating excellence in academic performance following the implementation of the instructional strategy. Among all science competencies, (SC) 3.5 Blood Flow recorded the highest learning gain of 4.72, signifying strong improvement and marking it as the area where the program was most effective. This was followed by (SC)
3.2 Blood Composition (3.28) and (SC) 3.3 Blood Vessels (3.04), both identified as substantial improvements. (SC)
3.4 Heart Anatomy demonstrated a notable

improvement with a gain of 2.15. Meanwhile, (SC) 3.7 Diseases Related to the Circulatory System (1.80) and (SC) 3.6 Blood Pressure (1.12) were categorized as having modest improvement. The lowest gain was observed in (SC) 3.1 Function of the Circulatory System, which had a gain of 0.70, interpreted as minimal improvement. These results suggest that while the program was largely successful in enhancing student learning, targeted support may be necessary for foundational competencies that showed lower gains.

The examination of learning progress in specific science skills reveals both the strengths and areas that need improvement in the intervention applied. Significant improvements in skills such as Blood Flow, Blood Composition, and Blood Vessels indicate that the instructional design has successfully promoted understanding in these topics. Conversely, the slight gain observed in the Function of the Circulatory System highlights the necessity to reassess how foundational concepts are presented and reinforced. This suggests that the intervention could benefit from enhanced scaffolding techniques, the inclusion of more interactive or visual resources, or differentiated instruction aimed at correcting initial misconceptions. By strengthening these aspects, we can ensure students develop a robust conceptual foundation before moving on to more intricate subjects, ultimately enhancing the program's effectiveness.

3.2. Student Performance Outcomes in Problem Based Learning (PBL) Assessed in Terms of Explanatory, Descriptive, Procedural and Personal Knowledge

Table 2. Summary of Student Performance

Knowledge Type	Beginning (0–10)	Developing (11–20)	Proficient (21–30)	Outstanding (31–40)	Mean	SD
Explanatory Knowledge	0 (0.0%)	38 (23.75%)	99 (61.88%)	23 (14.38%)	24.71	5.93
Descriptive Knowledge	0 (0.0%)	36 (22.5%)	97 (60.62%)	27 (16.88%)	24.82	6.01
Procedural Knowledge	0 (0.0%)	23 (14.38%)	115 (71.88%)	22 (13.75%)	26.34	5.02
Personal Knowledge	0 (0.0%)	73 (45.62%)	68 (42.5%)	19 (11.88%)	23.43	6.17

The computed mean scores and standard deviations reflect overall trends in knowledge acquisition across the four cognitive domains of the students. Among the knowledge types, Procedural Knowledge registered the highest mean score (M = 26.34, SD = 5.02), indicating stronger performance in strategy-based tasks. This was followed by Descriptive Knowledge (M = 24.82, SD = 6.01) and Explanatory Knowledge (M = 24.71, SD = 5.93), showing comparable results in students' ability to comprehend and explain concepts. Personal Knowledge recorded the lowest mean score (M = 23.43, SD = 6.17), along with the highest standard deviation, suggesting greater variation in students' performance and less consistent mastery in this domain. Despite differences in mean scores, all have a descriptive value of proficiency, meaning they all fall on the same score classification. Regarding score distribution, most students across the first three knowledge types were categorized under the Proficient level: 71.88% in Procedural, 60.62% in Descriptive, and 61.88% in Explanatory Knowledge. These results imply that students were largely competent in tasks that involved explanation, fact-finding, and strategy application. However, for Personal Knowledge, a higher proportion of students (45.62%) remained at the Developing level, with only 11.88% achieving Outstanding. This suggests a need for additional instructional support in activities that require ethical reasoning, reflection, and internalization of values.

These findings are consistent with the Problem-Based Learning (PBL) Taxonomy, which classifies tasks based on their cognitive focus. Explanatory and Descriptive Knowledge address the "*what*" of problems, facilitating comprehension, analysis, and synthesis; Procedural Knowledge relates to the "*how*" of problems, necessitating that learners analyze, plan, and evaluate; and Personal Knowledge deals with the "why" of problems, engaging with moral dilemmas and personal assessments. The strong results in procedural and descriptive tasks highlight the effectiveness of strategy- and fact-finding problems in fostering higher-order thinking skills. Conversely, the relatively lower performance in personal knowledge can likely be linked to the abstract and affective aspects of moral reasoning tasks, which demand deeper reflection and social interaction processes central to Piaget's and Vygotsky's constructivist theories. Therefore, incorporating more reflective, discussion-driven, and values-centered learning experiences could improve student outcomes in this area [47].

3.3. Significant Difference in Problem-Based Learning Outcomes According to Teaching Method Used- Explanation, Fact-finding, Strategy and Moral Dilemma

Based on the analysis conducted, students exposed to the Explanation Problem demonstrated the highest performance in Explanatory Knowledge (M = 3.20, SD = 0.56), followed by those in the Fact-Finding (M = 2.92, SD = 0.57) and Strategy Problem groups (M = 2.88, SD = 0.69). The Moral Dilemma group had the lowest mean (M = 2.63, SD = 0.49), suggesting that this approach may be less effective in enhancing explanation-based scientific understanding. These findings indicate that more structured, inquiry-oriented PBL methods might provide clearer scaffolds for **Table**

3. Post Hoc Comparisons Using Turkey's HSD (*Explanatory Knowledge*)

PBL Methods Compared	Mean Difference	SE	t	df	p	Interpretation
Explanation Problem vs. Fact-Finding Problem	-0.27	0.11	-2.5	75.98	0.07	Not statistically significant
Explanation Problem vs. Strategy Problem	-0.07	0.13	-0.57	66.68	0.94	Not statistically significant
Explanation Problem vs. Moral Dilemma	0.45	0.11	4.2	76.94	< .001	Statistically significant
Fact-Finding Problem vs. Strategy Problem	0.2	0.14	1.44	72.81	0.48	Not statistically significant
Fact-Finding Problem vs. Moral Dilemma	0.73	0.12	6.25	77.83	< .001	Statistically significant
Strategy Problem vs. Moral Dilemma	0.52	0.14	3.85	71.17	0.001	Statistically significant

developing explanation skills. The ANOVA yielded a statistically significant result, F(3, 156) = 6.55, p < .001, indicating that at least one group's performance differed significantly.

Table 4. Post Hoc Comparisons Using Games-Howell (*Descriptive Knowledge*)

PBL Methods Compared	Mean Difference	SE	t	p (Tukey)	Interpretation
Explanation of Problem vs. Fact-Finding Problem	0.28	0.13	2.11	0.15	Not statistically significant
Explanation of Problem vs. Strategy Problem	0.33	0.13	2.5	0.06	Not statistically significant
Explanation of Problem vs. Moral Dilemma	0.57	0.13	4.41	< .001	Statistically significant
Fact-Finding Problem vs. Strategy Problem	0.05	0.13	0.38	0.98	Not statistically significant
Fact-Finding Problem vs. Moral Dilemma	0.3	0.13	2.3	0.1	Not statistically significant
Strategy Problem vs. Moral Dilemma	0.25	0.13	1.92	0.22	Not statistically significant

The Tukey HSD post hoc analysis indicated that among the four-problem based learning (PBL) methods, a statistically significant difference was found only between the Explanation Problem and the Moral Dilemma group (p < .001). This shows that students engaged with explanation-based tasks achieved significantly higher Explanatory Knowledge scores. In contrast, all other pairwise comparisons—including those between Explanation and Fact-Finding (p = .15), and Explanation and Strategy (p = .06)—did not reveal statistically significant differences, indicating no meaningful variations among these methods.

This finding is consistent with the PBL taxonomy, emphasizing explanation problems as instruments for fostering learners' analytical, synthetic, and evaluative skills. These tasks illustrate Piaget's constructivist principle of constructing new cognitive frameworks through exploration and hypothesis testing. In contrast to moral dilemmas, which emphasize values and demand profound reflection, explanation problems provide more organized and cognitively straightforward learning routes, thereby proving more effective in improving scientific explanatory reasoning [4, 46]. ANOVA

revealed a statistically significant result, F(3, 156) = 12.23, *p* < .001, demonstrating that the type of PBL method had a meaningful impact on the Descriptive Knowledge of students. These findings imply that tasks focused on information gathering and understanding are more effective for enhancing Descriptive Knowledge. At the same time, activities involving moral reasoning may have a more limited effect in this cognitive area. The Games–Howell post hoc test, which adjusts for unequal variances, indicated that students using the Moral Dilemma method had significantly lower

Table 5. Post Hoc Comparisons Using Turkey's HSD (Procedural Knowledge)

PBL Methods Compared	Mean Difference	SE	t	p	Interpretation
Explanation Problem vs. Fact-Finding Problem	0.13	0.14	0.90	0.80	Not statistically significant
Explanation Problem vs. Strategy Problem	-0.50	0.14	-3.61	0.01	Statistically significant
Explanation Problem vs. Moral Dilemma	-0.60	0.14	-4.33	0.001	Statistically significant
Fact-Finding Problem vs. Strategy Problem	-0.63	0.14	-4.51	0.001	Statistically significant
Fact-Finding Problem vs. Moral Dilemma	-0.73	0.14	-5.23	0.001	Statistically significant
Strategy Problem vs. Moral Dilemma	-0.10	0.14	-0.72	0.89	Not statistically significant

Descriptive Knowledge scores compared to those in the Explanation Problem (p < .001), Fact-Finding Problem (p < .001), and Strategy Problem (p = .001) groups. However, there were no statistically significant differences among the top three methods—Explanation, Fact-Finding, and Strategy Problems. These findings suggest that while moral dilemmas may be less effective in enhancing students' skills in gathering, understanding, and synthesizing information, the other PBL methods yield similar outcomes in this cognitive area. Fact-finding tasks encourage learners to explore specific situations and connect new knowledge with what they already know, naturally fostering descriptive reasoning. These methods promote cognitive strategies and engage students in structured inquiry. In contrast, while moral dilemmas are significant for ethical assessment and value clarification, they may fail to build factual understanding since they prioritize reflective reasoning over information synthesis. These results indicate that to enhance descriptive knowledge, the focus should be on fact-driven and explanation-oriented PBL methods [4,9,46] **Table 5. Post Hoc Comparisons Using Turkey's HSD (*Procedural Knowledge*)**Procedural knowledge refers to a learner's capability to apply suitable strategies, processes, and actions when tackling a problem. It addresses the question of "*how*" and indicates students' proficiency in implementing and executing learned skills in structured scenarios. The Strategy Problem group achieved the highest mean (M = 3.02, SD = 0.55), suggesting that tasks involving detailed planning, sequencing, and action steps enhance the acquisition of procedural knowledge. Both the Explanation Problem (M = 2.42, SD = 0.55) and Fact- Finding Problem (M = 2.42, SD = 0.55) groups demonstrated moderate levels of procedural skill, indicating a sufficient but generalized understanding of applied tasks. In contrast, the Moral Dilemma group, primarily focused on encouraging personal reflection, scored the lowest (M = 2.30, SD = 0.46), implying limited reinforcement of actionable strategies in this approach. The result of one-way Among the four methods, the Fact-Finding Problem achieved the highest mean score (M = 3.23, SD = 0.53), followed by the Strategy Problem (M = 3.02, SD = 0.70), the Explanation Problem (M = 2.95, SD = 0.45), and the Moral Dilemma (M = 2.50, SD = 0.51).

Table 6. Post Hoc Comparisons Using Tukey's HSD (Personal Knowledge)

PBL Methods Compared	Mean Difference	SE	t	p	Interpretation
Explanation Problem vs. Fact-Finding Problem	~0.00	0.11	0.00	1.00	Not statistically significant
Explanation Problem vs. Strategy Problem	-0.35	0.11	-3.12	0.01	Statistically significant
Explanation Problem vs. Moral Dilemma	0.10	0.11	0.89	0.81	Not statistically significant
Fact-Finding Problem vs. Strategy Problem	-0.35	0.11	-3.12	0.01	Statistically significant
Fact-Finding Problem vs. Moral Dilemma	0.10	0.11	0.89	0.81	Not statistically significant
Strategy Problem vs. Moral Dilemma	0.45	0.11	4.01	< .001	Statistically significant

ANOVA confirmed a statistically significant difference in procedural knowledge scores among the four PBL methods, $F(3, 156) = 13.47$, $p < .001$.The post hoc result indicated that students scored significantly higher in Procedural Knowledge with the Strategy Problem compared to those in the Explanation Problem (p = .01), Fact-Finding Problem (p = .01), and Moral Dilemma (p < .001) groups. This suggests that PBL tasks emphasizing strategic thinking, planning and execution are particularly effective in fostering the measure learning outcomes. Moreover, the Explanation problem and Fact-finding problem both yielded statistically higher outcomes than Moral Dilemma. This implies that even PBL methods focused on explanation are more effective in achieving these outcomes than those on ethical reflection. Conversely, there was no significant difference in outcomes between the Explanation and Fact- Finding. This implies that these two approaches had a similar impact on the measured learning outcomes. Similarly, there was no significant difference between the Strategy Problem and Moral Dilemma groups (p < .001). This seemingly counterintuitive result, given that Strategy Problem has the higher mean, might be due to the specific nature of the measured outcomes.

The findings suggest that Strategy focused PBL tasks are

particularly enhancing the procedural knowledge compared to other PBL methods. This finding about strategic problem solving involves foreseeing possible problems and searching for procedural fixes. This implies that when students are given strategy problems, they become better at understanding concepts, carrying out strategic plans and adhering to precise steps and procedures; hence they offer a comprehensive analysis to arrive at an appropriate response [13].

The Strategy Problem group recorded the highest mean (M = 3.27, SD = 0.55), suggesting that tasks involving planning and execution may also foster evaluative thinking. The Explanation Problem (M = 2.92, SD = 0.53) and Fact-Finding Problem (M = 2.92, SD = 0.53) groups displayed moderate scores, indicating limited but relevant support for personal insight through structured reasoning. Notably, the Moral Dilemma group, aimed at enhancing Personal Knowledge, achieved the lowest score (M = 2.83, SD = 0.38). Although moral dilemmas are designed to promote personal evaluation, their abstract and introspective nature may necessitate prolonged engagement, guided reflection, or deeper discussion for learners to fully realize evaluative growth.

The Turkey HSD post hoc test indicated that students using the Strategy Problem method achieved notably higher Personal Knowledge scores than those in the Explanation Problem (p = .01), Fact-Finding Problem (p = .01), and Moral Dilemma (p < .001) groups. This implies that, although the Moral Dilemma method aims to improve evaluative thinking, strategy-focused tasks might afford more organized chances for students to exercise reflective judgment and decision-making in intricate situations. The Explanation and Fact-Finding groups showed no significant differences from each other or the Moral Dilemma group, which suggests that these approaches had similar effects on Personal Knowledge. These results emphasize that Strategy Problems, with their focus on "*how*" questions demanding analysis, planning, and evaluation, potentially encourage more meaningful interaction with personal and moral reasoning compared to dilemmas based strictly on abstract reflection.

Finally, the analysis indicated that the Problem-Based Learning (PBL) program successfully enhanced Personal Knowledge overall, although its effectiveness varied with the PBL method. The greatest improvements were noted among students working on Strategy Problems, demonstrating that structured, action-oriented tasks offered significant opportunities to practice evaluation, decision-making, and reflective thinking, essential elements of Personal Knowledge. In contrast, students confronted with Moral Dilemmas, which are theoretically aimed at fostering Personal Knowledge, performed the weakest. This suggests that this approach may need more guided facilitation, in-depth discussion, or emotional support for effectiveness. These findings underscore the necessity of thoughtfully selecting and implementing PBL strategies that align with cognitive objectives, while also enabling students to engage in meaningful higher-order, personal, and moral reasoning.

3.4 Experiences of Learners from Different Programs Using Problem-Based Learning (PBL)

The qualitative feedback collected from student interviews was examined using thematic analysis, which was based on a six-step procedure [14]. It involves data understanding, coding, topic identification, reviewing of themes, defining themes, and making reports. Open coding was used to identify recurring themes in student responses. The categorization and grouping of similar ideas have produced four main themes that reflect students' shared experiences and perspectives on the use of digital PBL. These evaluations provide insight into how students perceive problem-based learning (PBL) in their courses, highlighting its shortcomings, benefits, and areas for improvement. Four themes were: engagement and motivation, development of critical thinking skills, communication and digital literacy and navigation.

In engagement and motivation, students revealed that there is a significant effect on student's motivation and that students were motivated when they are able to actively make sense of their surroundings. A number of students mentioned how problem-based learning (PBL) affects their motivation in science. Student 1 said, *"I really enjoyed the strategy-based problems on digital platforms because these tasks gave students the opportunity to think outside the box and explore different options. The interactive tools found in IQ Candy, like the simulation, eBooks and word pop, help students stay engaged and it seems really interesting, not boring at all"* Student 2 explained how explanation problem provides him smooth understanding, saying. "*Explanation problems help me understand concepts better because I have to break things down in my own words. I also like the variety of resources found in my own words. I also like the variety of resources found in IQ Candy which makes the learning process a lot easier. I really love the teaching animation video included in the site.* " According to Barrows' Problem-Based Learning (PBL) taxonomy, the positive experiences of Students 1 and 2 are consistent with the development of motivation and the acquisition of content knowledge through structured explanation problems [46].

While Student 3 and Student 4 mentioned respectively: "*Fact finding problems are just okay. But sometimes, it feels like I am just goggling answers instead of understanding what the topic is really about. At first, I enjoyed it, but it gets confusing sometimes.*" and "I *think moral dilemmas are more interesting in class discussions but not in IQ Candy. There are times that I feel like I am alone at work. Without seeing my teacher and friends, it's really difficult to understand other answers and makes me bored.*" Students 3 and 4's description towards their experience with digital PBL, however, highlights areas in which self-directed learning and teamwork are deficient. Their loneliness suggests that, while digital PBL promotes independence, it could not be sufficient without sufficient social interaction and support. For digital PBL to fully accomplish Barrows' goals, meaningful collaboration and individual learning must be combined.

In development of critical thinking skills, student's narratives demonstrate active knowledge formation, which is essential for the growth of analytical and evaluative thinking, through real contact with complex digital concerns and the critical evaluation of data. This specific cognitive challenge with tasks like explanation and fact-finding provides ample support for Barrows' taxonomy of problem-based learning (PBL) goals, which highlights the development of problem-solving and reasoning abilities inherent in well-designed PBL activities, even in a digital format. Student 1 and 2 said, *"Doing the explanation task pushed me to become a more structured thinker. I was able to look for different options and break down complex ideas."* while Student 2 said, *"In my opinion, doing the PBL in IQ Candy, particularly the fact finding, is like doing the scavenger hunt but in a more exciting way since it's online. And yes, I believe my critical skills were improved as I had to evaluate the resources I found online".* Both Student 1's experience of being "*pushed... to become a more structured thinker*" and Student 2's requirement to "*evaluate the resources I found online*" align with Piaget's constructivist theory [2]. However, not everyone found it easy to develop critical thinking skills, particularly when social scaffolding was viewed as insufficient. Student 3 and 4 revealed,

"At first, I don't really understand what to do. But luckily, my group mates were very helpful and we had fun planning and making choices. It made us really think about what would happen next and why I should choose one thing over another. It's likely the same with Fyfe game where we figure out things so we could win the match." While Student 4 said, *"I will be honest, this*

is a bit difficult to understand. It was confusing and I don't know which decision I should make. Am I making the right or wrong decision? My groupmates talked online but I think it would be better if we talked about it in class with everybody and with you (the teacher)".

Although digital problem-based learning (PBL) employs individual participation to foster critical thinking in line with Piaget and Barrows, the results essentially highlight the critical role that direct facilitator support and strong social contact as emphasized by Vygotsky, play in enhancing the development of critical thinking. Critical thinking involves an active participation and acquiring skills of conceptualizing, analyzing, evaluating and applying it in real life situations. PBL has been proven to be effective in taking the part of developing one's critical thinking, problem solving skills and collaboration [14]. Problem Based Learning (PBL) taxonomy orders problems based on their cognitive emphasis. Explanatory and descriptive information addresses the "*what*" of the problems which aids comprehension, analysis and synthesis. Procedural talks about the "*how*" which encourages students to analyze, plan and evaluate. And, personal knowledge is engaged in self-assessment and making judgments [8].

These findings show the potential for digital PBL to enhance students' skills in problem solving, critical thinking and decision making particularly when given quality resources, structure thinking, enough information and guidance. Nonetheless, students showed limited improvement on their critical thinking skills related to personal knowledge which demands an in-depth reflection and interaction anchored to theories of Piaget and Vygotsky's constructivism. Thus, the integration of Thai values centered discussions, reflective practices and authentic decision-making experiences may enhance the development of students' personal knowledge.

Communication and collaboration are crucial elements for a method to be successful. Student 1 said,

"*We used our group chat a lot and we kept on sharing videos or websites that would help us solve the task. It's easier to talk with my groupmates.*" Also, Student 2 said, "*Sharing is caring, that's what I love on PBL when it is done online. It's easier to share our thoughts together. We asked each other questions like "Hey! Where did you get that? Does this fact make sense? Please check this out!*" These are the evidences that students gained effective group interaction both facilitated and challenged through digital PBL, according to the communication and collaboration responses. Students 1 and 2 highlighted how online platforms may promote quick peer-to-peer exchange and group problem-solving, while also appreciating the simplicity of digital tools for resource and idea sharing. The idea where knowledge is built through social interaction, strongly highlights the social constructivist theory by Vygotsky. It is directly supported by this effective communication. Students can provide mutual "scaffolding" within their Zone of Proximal Development (ZPD) by using digital technologies, which promotes growth and understanding between them. Moreover, Barrows' taxonomy of PBL goals, specifically, the development of critical communication and cooperation skills, is directly supported by these constructive experiences. However, Student 3 and 4 mentioned," *Sometimes we had a little argument because of too much information from different resources."* And "*I think it is easier to talk in the classroom in actual, real time and so we can see what everybody felt about it*."

These results point to a significant issue with applying Vygotsky's social constructivism to situations that are entirely digital. Social disagreement and the inability to digest more complex information due to a lack of urgency might lead to ineffective build-up of knowledge. Without adequate social support, it may be challenging for individual learners to overcome the cognitive imbalance because of excessive flood of information, even though they may make an effort to integrate new material. The digital environment can inconsistently weaken the strong collaborative dynamics required for PBL to be effective, despite its facilitative tools, making it more difficult to fully achieve Barrows' collaborative goals.

Students gain more meaningful experiences in digital PBL through collaborative work. It provides a wider opportunity for learners to express their thoughts and ideas within their peers. While some students may perceive PBL as a sheer volume of information and the difficulty of processing it, digital learning may not align with all learners' abilities to manage the learning process particularly in the absence of a classroom interaction and consultation [1,6].

Therefore, in order for digital PBL based learning to be effective, teacher-students need to maintain consistent communication.

The last theme underscores the role of digital literacy and navigation of digital PBL showed contradictory developments. Some students were found to be enjoying the application while others struggle. For example, Student 1 and 2 said,

"It was cool how we got to do our performance task since it's available online. But sometimes it was hard to understand what we were supposed to do. The instructions weren't always, like, super, clear, you

know."

"The IQ Candy was hard to use since it's our first time to use it. I think I will enjoy it if someone is guiding me in using this application."

These feedbacks are evidences that acknowledged the platform's potential to enhance learning and its challenges of the digital PBL. IQ candy was initially deemed "*hard to use*" by Student 2, who hoped there was "*someone guiding me*". Additionally, Student 1 noted that the instructions were not clear. This implies how crucial it is to provide guidance and assistance when implementing new digital technology. However, as stated by Students 3 and 4,

"It was more fun than doing our work in the classroom, it is easier to talk to friends and groupmates and there is a lot of information we can find online. I also like the feature of IQ candy where we can see our progress for each task although it's hard to use in the beginning."

"Well, I find it more interesting and organized. I can keep all my notes and go back to it anytime I like. I just wish that teacher could give us immediate feedback after submitting our work."

These contradictory findings support Piaget's constructivist theory by showing how pupils actively engage with and adapt to a new digital environment. The "*cool*" qualities and structure may change cognitive models and facilitate the processing of new information. The desire for direction effectively invokes Vygotsky's social constructivist theory. Student 2's desire for "*someone guiding me*" and Student 4's want for "*immediate feedback after submitting our work*" both emphasize how important it is for a More Knowledgeable Other (MKO), usually the teacher, to provide the required "*scaffolding*" within the Zone of Proximal Development (ZPD). This support is particularly crucial for understanding expectations and navigating intricate digital interfaces, as "the educational procedures expand to more thoroughly integrate technology and advancements [3]. If this explicit guidance is not given, the early usability problems might deter participants from participating in the actual PBL task.

The qualitative findings on digital literacy and navigation, particularly the low performing group, was observed in the Moral Dilemma and Fact- Finding groups, which support the quantitative results. Students' difficulties with the IQ Candy, such as confusing instructions (Student 1) and a lack of supervision (Student 2), probably caused cognitive overload and a decrease in task engagement, as evidenced by their relatively lower mean results. These challenges stress the importance of scaffolding, which is emphasized by Vygotsky's theory, especially in complex or unfamiliar digital contexts. On the other hand, the Explanatory group performed better because students 3 and 4 who were able to adapt and value the digital framework were more motivated and completed more homework. These results highlight how crucial digital literacy is to optimizing the effectiveness of digital problem- based learning (PBL).

When implementing digital PBL, it was discovered that concerns regarding digital literacy and navigation were crucial, particularly in some students who find it difficult to explore and use the digital platform used for PBL activities. The significance of digital literacy is becoming increasingly apparent as the educational procedures expand to more thoroughly integrate technology and advancements [43].

To achieve successful learning outcomes, integrating various digital tools with instructional methodologies must be utilized and this requires a deep understanding. When a teaching method and innovations were combined it securely improved the higher thinking skills of its learners. However, students and teachers in the Northeastern region of Thailand have comparatively lower levels of awareness and competency in modern educational technology usage compared to Bangkok, the country's center for technical growth [11].

When used with the appropriate resources and techniques, digital PBL improves critical thinking engagement and real-world connections. However, learning achievement and motivation maintenance require human connection, digital literacy, and right tool selection. Deep reflection exercises are crucial for developing personal knowledge and some PBL techniques must be adjusted for online learning. Through incorporating local values and encouraging cooperation among educators, students and stakeholders, digital PBL can be strengthened, especially in places with lower levels of technological capability.

4. CONCLUSIONS

From the study findings, the following conclusions are drawn.

1. Digital problem-based learning (PBL), when strategically implemented, significantly enhances students' academic performance, problem solving and critical thinking skills.
2. The test of result did not support the idea that students' problem-based learning outcomes which include the explanation, fact finding, strategy and moral dilemma vary meaningfully when grouped into different PBL methods.
3. Build a stronger scaffolding for abstract thinking, intentional facilitation during personal knowledge

tasks, integration of Thai culture and values so students can relate to, open communication of teachers and students and development of digital literacy among the students and teachers.

4. The results of the study showed that digital tools improve accessibility and engagement, but their true value lies in enabling worthwhile, introspective, and productive learning experiences. Therefore, a balanced, supervised, and contextually relevant approach to PBL and digital integration is necessary to build well-rounded learners.According to the students:

- Digital Problem Based Learning (PBL) is an effective and motivating tool. The integration of technology enhances their attention and engagement when compared to conventional teaching method. Moreover, it encourages students' development as autonomous learners and gives them the opportunity to engage with real world scenarios.
- Digital PBL has the ability to enhance problem solving, critical thinking and decision making when given topnotch resources, a methodical approach, sufficient information and guidance.
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5. RECOMMENDATION

The researcher comes up with the following recommendation after concluding the study.

1. Revise teaching methods to address misconceptions. Conduct formative assessments such quick polls, concept maps before and after lessons to identify and immediately address misconceptions.
2. Use interactive models and simulations for blood flow, heart anatomy and function to clarify complex functions of the circulatory system.
3. Make moral dilemma scenarios relatable to students. Provide clear learning objectives related to health, lifestyle choices of teenagers.
4. Facilitate structured group discussions with guided questions.
5. Sequence learning activities effectively. Start with basic anatomy and vocabulary before introducing to real world applications and complex processes.
6. Choose a digital platform that supports interactive content such as Phet Colorado, IQ Candy, EdPuzzle and with formative feedback.
7. Assess students' digital literacy before the semester begins and adjust the tool difficulty accordingly.
8. Provide video tutorials for students, for easy navigation of the digital platform.
9. Prioritize teacher-student and peer interaction in Digital PBL. Make sure to have a regular schedule for consultations or any questions. It can be in LINE, Messenger or Google chat**.**
10. Conduct training sessions for both Thai and International teachers, particularly in the Northeastern region of Thailand, to help them keep pace with the ongoing educational innovations emerging in the Central region of Thailand. This training should be done during semestral breaks.
11. Organize for a school visit opportunity especially schools with digital resources hub and facilities.

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