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The effectiveness of a scaffolded problem-based learning model to enhance systematic thinking and learning achievement in a Thai higher education database systems course

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Abstract: The global digital skills gap, particularly in roles such as data engineering and system analysis, highlights the necessity for effective pedagogy in foundational courses like database systems. Students often encounter difficulties with the higher-order thinking skills (HOTS) required for database design and SQL programming. Consequently, this study developed and evaluated the effectiveness of a Scaffolded Problem-Based Learning (PBL) model, termed the 'KRIS model,' aimed at improving students' systematic thinking and academic achievement. The KRIS model was constructed through a synthesis of PBL, scaffolding literature, and prior research on student perceptions. It comprises four core components: (K) Knowledge base support, (R) Responsibility for self and collaboration, (I) Inter-connectedness in team interaction, and (S) Systematic process. The model was validated by a panel of seven experts specializing in database systems, PBL, and assessment. A quasi-experimental design was employed, comparing an experimental group (n=60) taught with the KRIS model against a control group (n=59) taught using traditional methods. Expert validation confirmed the model's high quality and suitability. The experimental results indicated that students in the experimental group, who learned through the KRIS Scaffolded PBL model, achieved significantly higher scores in both systematic thinking and academic achievement than those in the control group. The KRIS Scaffolded PBL model is an effective instructional strategy for enhancing higher-order cognitive outcomes in database education. It offers a structured framework to support learners, fostering systematic thinking and practical skills essential for the modern ICT (information communications technology) industry.

Keywords: *Database systems, Higher education, Learning achievement, Problem-based learning, Scaffolding, Systematic thinking.*

1. Introduction

The global digital economy faces a critical shortage of skilled personnel in key roles such as software developer, data engineer, system analyst, and AI-ML engineer (Artificial Intelligence and Machine Learning) [1, 2]. These professions, outlined in international skills frameworks like SFIA (Skills Framework for the Information Age) 9, require a strong foundation in data management, systems development, and software engineering. Database systems are a cornerstone course underpinning these competencies, providing essential knowledge for navigating the System Development Life Cycle (SDLC) [3, 4]. Mastery of specific skills within this course, namely, database design using Entity/Relationship Diagrams (E/R Diagrams) [5-7] and data manipulation via SQL programming [6], is essential for success in fields like data engineering and business intelligence [8, 9].

A key challenge remains, however. A primary reason for this skill gap is the uneven development of students' higher-order thinking skills (HOTS), which is consistent with the *analysis*, *evaluation*, and *creation* levels of the revised Bloom's taxonomy [10]. These cognitive levels are required to apply

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knowledge and skills to complex, real-world problems, such as designing a normalized database from a set of user requirements or writing a complex SQL query to answer a real business problem. Passive, traditional instructional methods often fail to develop such advanced skills, resulting in shallow learning and the inability to apply knowledge in practical contexts or novel situations [11].

A paradigm shift toward engaging, student-centered pedagogies is necessary to address this problem. One such pedagogy is problem-based learning (PBL), which is rooted in constructivist principles [12]. It is intended to engage students in learning through complex, contextualized problem scenarios, work collaboratively to construct knowledge, and promote students' problem-solving and lifelong learning capacities, which include understanding, knowledge, and long-term memory retention [13]. However, a practical implementation of PBL is often nontrivial because of the students' lack of prerequisite knowledge or self-directed learning skills. Scaffolding, rooted in Vygotsky's concept of the Zone of Proximal Development (ZPD) [14] provides temporary support that helps learners accomplish tasks they could not complete independently. These supports are gradually removed as the learner's competence increases [15, 16].

The following research objectives (ROs), research questions (RQs), and research hypotheses guide this experimental study: RO1: To study the effectiveness of a Scaffolded PBL model on enhancing students' systematic thinking and learning achievement [17].

RO2: To compare the systematic thinking and learning achievement of students in the experimental and control groups after learning through the Scaffolded PBL model.

RQ1: How does the Scaffolded PBL (KRIS) improve students' systematic thinking when solving problems in database design and SQL programming?

RQ2: To what degree does the Scaffolded PBL (KRIS) model enhance students' database systems academic achievement compared to traditional instruction?

RQ3: Is there a statistically significant difference in systematic thinking and academic achievement between students taught using the Scaffolded PBL model instead of the traditional model?

Research Hypothesis.

Systematic thinking skills of the students in the experimental group, in which the Scaffolded PBL model is applied, will be significantly higher than those in the control group, in which teaching with traditional methods is carried out (small groups).

$H_{2:}$ Academic achievement of the students in the experimental group, in which the Scaffolded PBL model is applied, will be significantly higher than that of the students in the control group, in which teaching is carried out with traditional methods (whole class).

2. Literature Review

This review establishes the theoretical foundation for the study by examining the core concepts of PBL and scaffolding, and their integration into the proposed instructional model.

2.1. Problem-Based Learning (PBL)

Problem-based learning (PBL) is a learner-centered pedagogy in which students gain knowledge about a subject through the experience of solving an open-ended problem found in trigger material [18]. The process promotes students' active learning, constructing knowledge, which ultimately enhances their higher-order thinking skills (HOTS) [19]. It is an active learning style based on the constructivist theory of learning. PBL helps students develop skills used for their future practice. It enhances critical appraisal, literature retrieval, and encourages ongoing learning within a team environment [18]. It can also incorporate HOTS, which helps students analyze, evaluate, and create [20].

The collaborative nature of the process also reflects Vygotsky's social constructivist view that learning is a group process and knowledge construction, meaning that meaning-making is never a solitary activity. However, it is a collaborative process [14]. There are various ways to execute it, but the overall steps of the PBL process are often structured. As seen in Table 1, familiar patterns can be observed across many models, such as Wood [18], Moust et al. [19] and Knowles [21, 22]. In most models of the PBL process, learners begin by exploring a problem, progress through a self-directed learning phase, and conclude with a synthesis and reporting phase. These steps are designed to move learners toward synthesizing knowledge and solutions, which develop a structured and flexible method of successful critical thinking and problem solving in many educational areas, as applied in several Thai studies in recent years [23].

Table 1.
A Comparative Overview of PBL Process Steps.

Phase	Wood [18] Problem-Based Learning (PBL)	Moust, et al. [19] Problem-Based Learning (PBL)	Knowles [21, 22] Self-Directed Learning (SDL)
Problem Exploration	Identify and clarify unfamiliar terms	Discuss the case	Clarify terms/Setting
Problem Definition	Define the problem	Identify the questions	Define the problem
Analysis & Ideation	Brainstorming & arranging explanations	Brainstorm	Analyze the problem
Structuring	Formulate learning objectives	Analyze and structure	Re-structure the problem systematically
Learning Objectives	-	Formulate learning objectives	Formulate learning objectives
Self-Directed Learning	Private study	Do an independent study	Self-directed learning
Synthesis & Reporting	Group shares results	Discuss the findings	Report back & synthesize

2.2. Scaffolding in Educational Contexts

Scaffolding is an instructional technique in which Vygotsky's idea of the Zone of Proximal Development is integrated into the classroom (ZPD). Vygotsky defined the Zone of Proximal Development as the distance between a learner's developmental level, as determined by independent problem-solving, and their potential level, determined through problem-solving under a teacher's guidance or in collaboration with more advanced peers [14]. Scaffolding provides the temporary support structures to assist the learner in accomplishing a task or developing new understandings, so these can be taken away over time when they are no longer needed (the gradual removal of these structures is called "fading") as the learner develops autonomous learning strategies [15, 16].

It provides the help necessary to make students who do not have the required knowledge or skills to deal with difficult materials, such as database design and SQL programming. The purpose of scaffolding is not to solve the task for the learner but to give guidance by which the learner will know strategies that will later help them tackle the complexity of the materials alone [24].

Table 2.
Core Elements of Instructional Scaffolding Across Theoretical Models

Scaffolding Function	Wood et al. [25]	Van de Pol et al. [16]	McKenzie [26]
Engagement & Diagnosis	Recruitment	Diagnosis	Provide Clear Directions, Clarify Purpose
Task Support	Reduction in degrees of freedom	-	Keep Students on Task, Reduce Uncertainty
Guidance & Modeling	Direction maintenance, Demonstration	Contingency	Point to Worthy Sources, Deliver Efficiency
Cognitive Support	Marking critical features	-	Offer Assessment to Clarify Expectations
Affective Support	Frustration control	-	Create Momentum
Fading & Transfer	-	Fading, Transfer of Responsibility	-

As shown in Table 2, scaffolding encompasses many methods, from recruiting student interest and reducing the degree of freedom of the task to using modeling to provide an idealization of the act and offering formative feedback [16, 25, 26]. Successful scaffolding leads to the formation of higher-order thinking, in which students can meet the learning goal on their own by helping a learner overcome the gap between their current ability and the intended learning goal, and it promotes self-regulation and long-term knowledge retention.

2.3. The Integration of PBL and Scaffolding: The KRIS Model

While PBL provides a practical framework for helping students engage in authentic problem solving, it cannot support students in gaining meaningful problem-solving (ill-structured) skills. On the other hand, scaffolding will be ineffective if we help students solve a particular problem by breaking it into meaningful parts and guiding them through solving the problem (structured problems).

As such, the study combines the two pedagogic approaches into a unified model: the KRIS Scaffolded PBL Model. The model consists of four components arising directly from the literature:

- K (Knowledge Base Support): Provides the necessary resources and underpinning knowledge structures [26] that students need in order to properly investigate and interrogate the PBL problem and avoid cognitive overload.
- R (Responsibility for Self and Collaboration): Encompasses the fundamental PBL principle of self-directed learning and the scaffolding function of keeping on course [25] that involves ensuring that students take responsibility for their learning individually and within the team.
- I (Interconnectedness in Team Interaction): Rooted in the social constructivist basis for both PBL and scaffolding, it demonstrates the importance of collaborative dialogue and peer support [14, 19] within the team in enabling students to construct knowledge.
- S (Systematic Process): Provides a structured workflow (e.g., the PBL steps in Table 1) to scaffold students' problem-solving work, guiding them from initial possible confusion to a systematic and well-reasoned approach.

The KRIS model aims at systematically promoting systematic thinking skills and academic achievements in complex domains like database systems by coupling motivational and cognitive engagement found in PBL with supportive scaffolding.

2.4. Research Gap

This synthesis of literature reveals a critical research gap. While the individual benefits of PBL for database education [27, 28] and the theoretical importance of scaffolding for supporting diverse learners [16, 25, 26] are well-established, there is a scarcity of research that systematically integrates these two approaches into a cohesive instructional model specifically for technical courses like Database Systems. Furthermore, existing studies often focus on academic achievement or generic problem-solving skills, leaving a gap in understanding the impact of such integrated models on systematic thinking, a critical competency for database design and SQL programming that aligns directly with higher-order cognitive processes [7, 10].

Most importantly, there is a lack of empirical evidence from quasi-experimental studies that test the effectiveness of such a scaffolded PBL model in a real classroom setting, particularly within the Thai higher education context, where developing higher-order thinking skills is a national priority [8]. This study aims to fill this gap by developing, validating, and empirically testing the "KRIS" model, a scaffolded PBL framework designed to enhance systematic thinking and academic achievement in a database systems course.

3. Methods

This study employed a two-phase, sequential explanatory mixed-methods design [29]. Phase 1 involved developing and validating the instructional model, while Phase 2 consisted of a quasi-

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experiment to test the model's effectiveness.

3.1. Research Design
The research was undertaken using two processes:
Process 1: The development and expert validation of the KRIS Scaffolded PBL model [17].
Process 2: A quasi-experimental study comparing the learning outcomes of an experimental group (taught with the new model) and a control group (taught with traditional methods) [12].

3.2. Phase 1: Model Development and Validation
Phase 1 entailed two steps. These were:

3.2.1. Model Development (Step 1)
The KRIS Scaffolded PBL model was developed systematically by synthesizing relevant literature. Data sources included domestic and international journals, textbooks, and research articles on PBL and scaffolding methodologies. A content analysis form was used to extract and record key information. The synthesis of these findings led to the initial design of the instructional model, which integrates the core principles of both PBL and scaffolding into a cohesive framework.

3.2.2. Expert Validation (Step 2)
The initial model was validated by seven purposively selected experts in relevant fields. The panel comprised:

- Three experts in database systems content.
- Three experts in active learning, specifically PBL and Scaffolding.
- One expert in educational assessment.

The experts critically reviewed the model using a structured evaluation form. Their qualitative feedback was analyzed using content analysis, and their quantitative ratings were used to establish the model's validity. The model was refined based on this expert feedback before proceeding to the experimental phase.

3.3. Phase 2: Quasi-Experimental Implementation
3.3.1. Participants and Sampling
We experimented with undergraduate students from the Faculty of Science at KMITL in Thailand. All participants were enrolled in the *Database Systems course* during the 2024 academic year. We selected two classes through a random lottery from six classes. One class was assigned to an experimental group (n=60) taught with the KRIS Scaffolded PBL model, while the other class served as the control group (n=59) and received traditional, lecture-based instruction.

3.3.2. Research Instruments
Two primary instruments were used to measure the outcomes:
Learning Achievement Test (database design): This instrument used an analytical scoring rubric to assess the database design process. The rubric demonstrated high content validity, with an item congruence (IOC) index between 0.60 and 1.00. Inter-rater reliability (IRR), calculated using Pearson's product-moment correlation coefficient (r) between two course instructors, was 0.84, indicating strong consistency in scoring.
Systematic Thinking Test (SQL Programming): This instrument used a similar analytical rubric to assess systematic thinking as demonstrated through SQL code. It also showed high content validity (IOC = 0.60-1.00) and strong inter-rater reliability (IRR = 0.83).

3.3.3. Data Collection Procedure

The procedure was identical for both groups, differing only in the instructional method:

1) Both groups completed a pre-test on learning achievement.
2) The experimental group was taught using the developed Scaffolded PBL model.
3) The control group used traditional teaching methods such as lectures, instructor demonstrations, and student practice.
4) After the intervention, both groups completed post-tests for systematic thinking and learning achievement.

3.3.4. Data Analysis

To compare the post-intervention outcomes between the experimental and control groups and control for potential Type I error, a One-Way Multivariate Analysis of Variance (MANOVA) was conducted [12]. The dependent variables were post-test scores in systematic thinking and learning achievement, and the independent variable was the group (experimental vs. control).

After controlling for other effects, partial η^2 (eta squared) was used to report effect sizes, representing the proportion of variance in the dependent variables explained by the instructional model. Reporting partial η^2 provides information on the practical significance of the findings beyond the statistical significance indicated by p-values. According to Cohen's guidelines, .01, .06, and .14 values correspond to small, medium, and large effects, respectively.

4. Results

4.1. Phase 1: The Developed KRIS Scaffolded PBL Model

The development and validation process resulted in the finalized KRIS Scaffolded PBL model. The model's name, "KRIS," is an acronym derived from its four core components, each detailed in Table 3 with comprehensive theoretical grounding.

The expert validation phase yielded highly positive results. The seven experts rated the model highly on its utility, feasibility, appropriateness, and accuracy, confirming its quality and implementation readiness [30, 31].

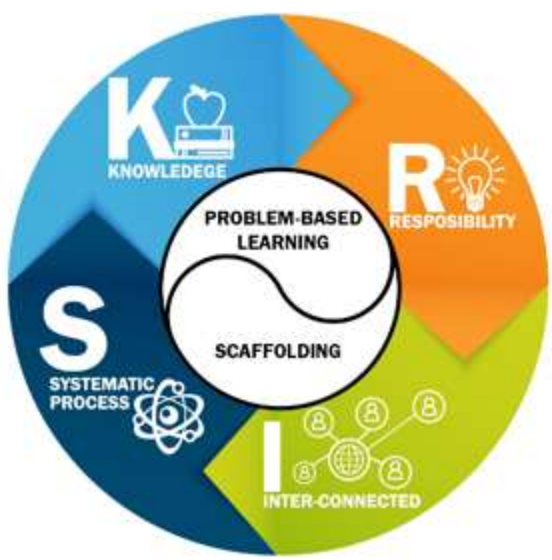

Figure 1.
The Scaffolded Problem-Based Learning (KRIS) Model.

Table 3.
Components and Descriptions of the Scaffolded PBL (KRIS) Model.

Key	Component	Description
K	Knowledge Base Support	Supports the learner's knowledge construction based on cognitive and social constructivist principles [32], including case studies and relevant learning resources. Scaffolding assists learners with limited prior knowledge within the Zone of Proximal Development (ZPD) [14], enhancing understanding and problem-solving skills.
R	Responsibility	Promotes self-responsibility and collaboration, making students aware of their duties to themselves and their group. Includes instructor coaching that encourages and accelerates learning without directly providing solutions.
I	Inter-connectedness	Builds team interaction to support collaborative problem-solving [33], fostering effective communication through social network platforms and synchronous and asynchronous methods [34].
S	Systematic Process	Applies the Plan–Do–Check–Act (PDCA) continuous improvement cycle [35] across the System Development Life Cycle (SDLC), integrating self-assessment and rubric-based evaluation to ensure fairness and transparency in assessing individual and group work quality.

4.2. Phase 2: Quasi-Experimental Results

4.2.1. Descriptive Statistics

Table 4 details the experimental and control groups' academic achievement and systematic thinking scores, with students in the experimental group taught with the Scaffolded PBL model achieving higher mean scores in academic achievement (78.56 vs. 66.92) and systematic thinking (82.35 vs. 56.01) compared to the control group taught with traditional methods.

Table 4.
Academic Achievement and Systematic Thinking Mean and Standard Deviation (SD) Scores.

Group	**n**	**Academic Achievement (Max=100)**		**Systematic Thinking (Max=100)**	
		Mean	**SD**	**Mean**	**SD**
Experimental	60	78.56	10.37	82.35	14.42
Control	59	66.92	10.53	56.01	21.08

Note. n = Number of individuals, M = Mean, SD = Standard deviation.

4.2.2. Preliminary Assumption Testing for MANOVA

Before conducting the One-Way MANOVA, preliminary tests were performed to verify the statistical assumptions, as shown in Table 5. Bartlett's Test of Sphericity was significant ($p < .05$), indicating that the dependent variables are correlated and suitable for MANOVA [36]. The PPMCC between academic achievement and systematic thinking was $r = 0.66$, falling within the acceptable range of 0.20 to 0.80, indicating a moderate relationship without multicollinearity concerns.

Table 5.
Statistics for Preliminary Examination of MANOVA Assumptions.

Test	**Statistics**	**Test Results**
Multicollinearity	Bartlett's Test of Sphericity (Sig. < 0.05)	Likelihood Ratio = 0.00, Approx. Chi-Square = 69.95, df = 2, Sig. = 0.00*
Relationship between dependent variables	Pearson correlation ($0.20 \leq r \geq 0.80$)	$r = 0.66$, Sig. < 0.00

4.2.3. One-Way MANOVA Results

Table 6's One-Way MANOVA revealed a statistically significant overall effect of the instructional model on the combined dependent variables (academic achievement and systematic thinking), Wilks' Lambda = 0.631, $F(2, 116) = 33.961$, $p < .001$, partial $\eta^2 = 0.369$.

Table 6.
Multivariate Analysis of Variance (MANOVA) Results for Learning Outcomes

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial η²
Intercept	Wilks' Lambda	0.020	2862.703	2	116	0.000
Group	Wilks' Lambda	0.631	33.961	2	116	0.000

Follow-up univariate ANOVAs showed significant differences between groups for both dependent variables:

For Academic Achievement: $F(1, 117) = 36.934$, $p < .001$, partial $\eta^2 = 0.240$ (1)

For Systematic Thinking: $F(1, 117) = 63.460$, $p < .001$, partial $\eta^2 = 0.352$ (2)

The effect sizes (partial η^2) indicate that the instructional KRIS model accounted for 24.0% of the variance in academic achievement and 35.2% in systematic thinking, representing significant practical effects according to Cohen's conventions. These results provide strong empirical evidence supporting the research hypothesis that the Scaffolded PBL (KRIS) model significantly enhances academic achievement and systematic thinking compared to traditional instruction.

5. Discussion

This study developed and empirically tested the effectiveness of the KRIS Scaffolded PBL Model for teaching database systems. The results provide compelling evidence for the model's efficacy in enhancing academic achievement and systematic thinking skills.

The experimental groups' significant improvements ($p < .001$ for both outcomes) with large effect sizes (partial $\eta^2 = 0.240$ for achievement; 0.352 for systematic thinking) demonstrate the practical importance of the KRIS model. These findings align with previous research on scaffolded PBL [16, 17] but extend them by providing a structured framework tailored explicitly for database education [37].

The KRIS model's success can be attributed to its integrated components. The *knowledge base support* (K) likely helped bridge the zone of proximal development for students with varying prerequisite knowledge. Simultaneously, the *responsibility* factor (R) fostered the self-directed learning essential for PBL success [38]. The *interconnectedness* element (I) facilitated the social constructivist learning environment crucial for complex problem-solving, and the *systematic process* (S) provided the structured approach needed for database design tasks within the SDLC framework [3].

The substantially larger effect on systematic thinking (35.2% of variance explained) compared to academic achievement (24.0% of variance) suggests that the model is particularly effective for developing higher-order cognitive skills. This is especially relevant given the identified gaps in Thai students' HOTS abilities [39] and aligns with national educational priorities.

These findings have important implications for addressing the global digital skills shortage in roles requiring strong analytical and systematic problem-solving capabilities, as well as computational thinking skills essential for careers as data engineers and system analysts.

6. Conclusions

This study successfully developed and validated the KRIS Scaffolded PBL Model, comprising four integrated components: knowledge base support, responsibility, interconnectedness, and systematic process.

The experimental results demonstrate that:

1) Compared to traditional instruction, the KRIS model significantly enhances students' academic achievement in database systems.

2) The model produces even greater improvements in systematic thinking abilities, which are crucial for success in technical ICT roles.

The KRIS model provides educators with an evidence-based framework for implementing scaffolded PBL in technical courses, particularly those requiring complex problem-solving and systematic approaches. By integrating structured support with authentic problem-solving, the model addresses common challenges in database education while developing the higher-order thinking skills demanded by the modern workforce.

This study was conducted within a single university context, focusing on database systems. Future research should examine the model's effectiveness across different institutions, cultural contexts, and technical disciplines. Longitudinal studies tracking the retention of learning gains and career outcomes would also be valuable.

7. Practical Implications

Educators should consider adopting scaffolded PBL approaches for technical courses, ensuring adequate knowledge support structures and systematic processes. Curriculum designers can use the KRIS framework to develop more effective learning experiences, bridging the theoretical knowledge and practical application gap.

Institutional Review Board Statement:

This research involved human participants and was conducted in accordance with the Declaration of Helsinki (revised 2013). All participants provided informed consent. The study protocol was exempt from institutional ethics review under Thailand's TSRI Guidance No. 3(3), as the research was conducted anonymously, did not collect identifiable information, involved no intervention, and posed no risk to participants' physical or mental integrity [40].

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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