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Kolb's Experiential Learning Model in STEM Education: A Theoretical and Empirical Study with Ninth Grade Students

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Abstract

Background: Vietnam's educational reform emphasizes competency-based learning to enhance problem-solving skills. Kolb's Experiential Learning Model (ELM) provides a structured approach to integrating hands-on activities in STEM education, but its effectiveness in secondary education remains underexplored. Purpose: This study examines the applicability of Kolb's extreme learning machine (ELM) in STEM education and evaluates its impact on ninth-grade students' problem-solving skills through experiential learning. This study investigates whether hands-on activities improve students' ability to analyze problems, propose solutions, and apply scientific concepts.Method: A quasi-experimental mixed-methods design was used with 334 ninth-grade students from two secondary schools. The experimental group engaged in a STEM activity constructing a "Revolving Lantern" to explore energy transformation. Data were collected through pre- and post-tests, teacher observations and interviews. Pearson's correlation and confirmatory factor analysis (CFA) were conducted to assess skill development.Results: The experimental group showed significant improvement in design skills by 150%, problem analysis by 33.33%, and implementation by 33.33%. Pearson's correlation analysis indicated a moderate relationship between experiential learning stages and problem-solving abilities, with Concrete Experience having the strongest effect. The CFA confirmed the reliability of the assessment framework.Conclusions: Kolb's ELM enhanced problem-solving skills in STEM education by connecting theory with practice. These findings support its integration into secondary education to foster critical thinking skills and creativity. Future research should explore the long-term impacts and broader applicability of this method.

Keywords: *Experiential Learning, STEM Education, Energy Transformation, Problem-Solving Skills, Revolving Lantern Model*

INTRODUCTION

In the context of modern education, the connection between theory and practice to improve students' learning efficiency and problem-solving skills has become a top priority (Kolb, 1984; Dewey, 1938). In response, STEM education combined with experiential education methods has become an important trend in teaching and learning. According to Kolb's (1984) Experiential Learning Theory (ELT), the learning process takes place in four stages: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. This model has been widely applied in many educational contexts and has been shown to help students develop critical thinking, problem-solving, and knowledge application skills (Burch et al., 2012; Burch et al., 2019). However, the effectiveness of ELT in STEM education has not been fully studied, particularly in the context of secondary education in Vietnam. STEM education has been shown to have a positive impact on students' learning and skill development (Bybee 2013; Kelley and Knowles 2016). Studies have shown that STEM approaches help students develop systems, critical, and teamwork skills (Hallström et al. 2023). However, most studies have focused on STEM education at the university or vocational level, while research on the impact of STEM combined with experiential learning at the secondary level is limited (Dimopoulou & Gasparatou, 2023). Furthermore, many studies have not considered cultural factors in STEM education, although recent studies have emphasized that integrating cultural contexts into education can increase student motivation and engagement (. F, 2020; Moscoso, J. A, 2018). Meanwhile, Vietnamese education is in the process of reforming the general education curriculum to develop learners' capacities, encourage active teaching methods, and link them to practice (Ministry of Education and Training, 2018). However, the application of experiential education models to STEM has not been thoroughly researched and still faces many challenges, especially in developing learning activities appropriate for the Vietnamese cultural context.

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Kurt Lewin, a pioneering psychologist, developed the theory of experiential learning through his "learning cycle" model (Lewin, 1946). He argued that learning is a continuous process that includes concrete experiences, observation and reflection, abstract concept formation, and experimentation in new situations. This model has deeply influenced modern approaches to education, especially the design of experiential learning programmes.

Kolb outlined the stages of experiential learning, but the model provides little practical guidance for implementing learning activities or assessing experiential learning outcomes in different educational contexts. To examine this issue, we tested the topic "Energy Conversion" through the STEM experiential activity of building a "Revolving Lantern." This topic is not only consistent with the content of the Grade 9 Natural Science program, but also provides an excellent opportunity to test the effectiveness of experiential education in improving students' problem-solving skills. Furthermore, this study hopes to contribute to the understanding of the role of hands-on experiences in promoting effective STEM education.

CONTRIBUTION TO THE LITERATURE

This study demonstrated the effectiveness of Kolb's Experiential Learning Model (ELM) in STEM education, which enhances students' problem-solving skills through hands-on learning. By designing and constructing a "Revolving Lantern," an integral part of Vietnam's Mid-Autumn - "The Children's Festival" students engaged in a meaningful exploration of energy transformation, linking scientific principles with cultural heritage. This study highlights the importance of integrating cultural contexts into STEM education to enhance engagement and learning outcomes.

Research questions:

RQ1. Does Kolb's model improve problem-solving skills?

RQ2. Is the effectiveness of the experiential learning model greater than that of traditional teaching methods?

RQ3. Is Kolb's experiential learning model appropriate for STEM education?

Theoretical Model

John Dewey and Kurt Lewin were pioneers in the study of experiential learning, each offering a unique perspective on how to personalize learning through experience.

Dewey's learning model (Figure 1) is based on two core principles: Experiences build on each other over time

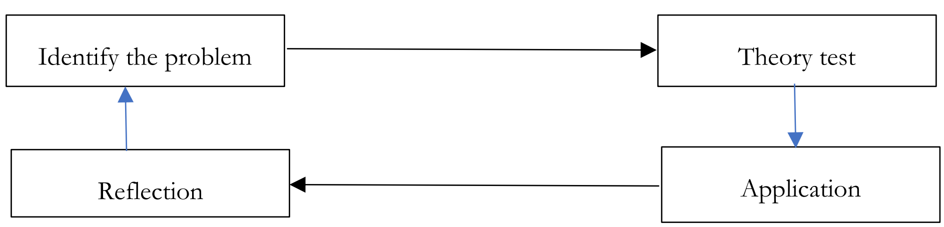

Figure 1.

Dewey's model (1938)

(continuity). Learning occurs through interactions between learners and their environments. The learning process involves experiencing, reflecting, and applying knowledge to new situations without following a rigid structure. Dewey emphasized holistic, lifelong learning that is socially and ethically connected.

Lewin's learning model (Figure 2) consists of the following stages: identifying the problem, proposing solutions, implementing the proposed solutions, evaluating the results, and drawing on personal experience (new knowledge).

Lewin's model emphasizes solving practical problems and producing tangible results. Learning occurs through the interaction of planning, doing, and reflecting. This model is appropriate for real-world improvement projects in which testing and adjusting solutions are necessary.

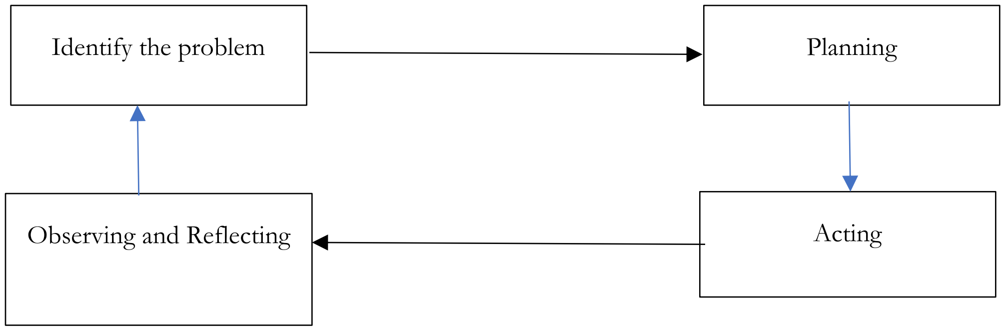

Figure 2.

Lewin 's model (1946)

Lewin’s model is an effective tool for solving practical problems and improving practice, particularly in areas that focus on group or class activities. However, compared to Kolb’s model, it is less flexible in contexts that require individualization and close integration of theory and practice, such as in the context of STEM education.

Recently, a number of studies have evaluated the effectiveness of connecting scientific theory with practice through experiential learning, according to Kolb's model in STEM education.

Ting's (2016) study demonstrated that using the Kolb model in STEM activities such as planning and implementing science projects significantly improved students' critical thinking skills and teamwork ability. At the same time, another study by Schön (1987) on reflection theory showed that encouraging students to reflect after each activity not only reinforced scientific knowledge, but also helped them better understand their own learning process. These studies confirm that the Kolb model not only enhances the ability to absorb theory, but also promotes practical applications in STEM education. In particular, Zydney et al. (2012) showed that applying the stages of Kolb's model in STEM design projects helps students develop problem-solving skills by analyzing situations, planning, and implementing specific solutions. In addition, Bell's (2010) study emphasized that students participating in experiential learning activities not only improved their learning outcomes, but also

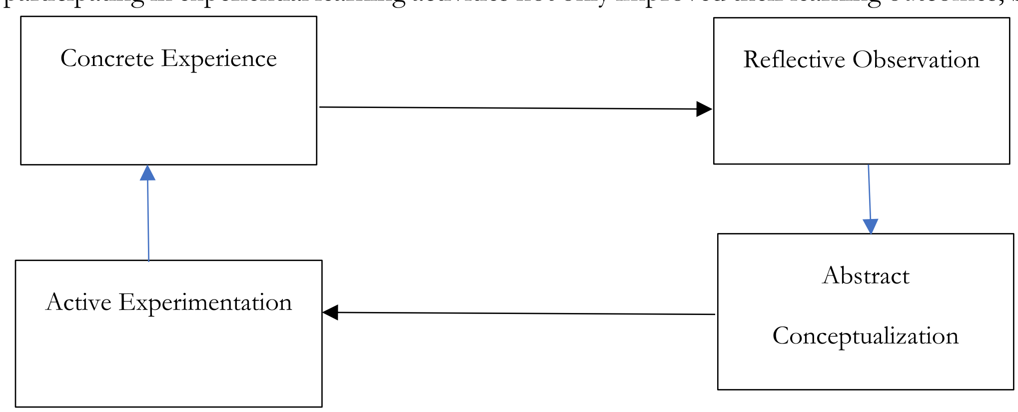

Figure 3.

Kolb 's model (1984)

became more confident in facing real-world challenges. According to Kolb, learning is the process of transforming experiences through a cycle consisting of four stages: Concrete Experience; Reflective Observation; Abstract Conceptualization; Active Experimentation (Figure 3).

In the concrete experience phase, students are directly involved in projects or experiments, providing opportunities to identify and understand problems. Then, in the observation and reflection phase, students are encouraged to record and analyze the implementation steps as well as the results achieved, helping clarify the causes and effects of the solutions.

The abstract conceptualization stage allows students to synthesize their experiences into new theories or strategies, which they then apply in the active experimentation stage, where they continue to test optimized solutions. The cycle between these stages not only helps students solve the current problem but also prepares them for future challenges. In the concrete experience stage, students directly participate in real-world experiments or projects such as building a renewable energy model or testing physical phenomena. Then, in the reflective observation stage, they are encouraged to take notes, analyze the results, and discuss with peers or teachers to better understand what happened. Next, the abstract conceptualization stage allows students to synthesize their observations into scientific concepts or laws, such as understanding the principle of the conservation of energy through practice.

The rotation between stages not only helps students grasp scientific knowledge but also develops critical and creative thinking skills in STEM. First, in the concrete experience stage, students directly participate in real-world experiments or projects, such as building a model of the conversion of heat energy to mechanical energy through the construction of a "Revolving Lantern." Then, in the reflective observation stage, students are encouraged to take notes, analyze the results, and discuss with friends or teachers to better understand what happened in the "Revolving Lantern." Next, the abstract conceptualization stage allows students to synthesize observations into scientific concepts or laws, such as understanding the principle of conservation of energy through the practice of making a "Revolving Lantern." Finally, in the active experimentation phase, students applied the concepts they had learned to solve new problems, such as designing a renewable energy system in a real-world context.

RESEARCH DESIGN AND METHODS

Background

This study used a mixed method, including theoretical and empirical research.

In terms of theoretical research, based on Kolb's Experiential Learning Model (Figure 3), we built a STEM teaching process that is suitable for research purposes. We then used this process to teach and evaluate the impact of the theoretical model on students' problem-solving skills in STEM teaching.

Empirical research aims to test and evaluate the suitability of theoretical research results for research purposes and teaching practices in high schools. An experimental design was used to test the development of students' problem-solving skills and demonstrate the effectiveness of STEM teaching using Kolb's Experiential Learning Model approach.

An experimental design with 334 ninth-grade students from two secondary schools and teachers voluntarily participated in this study, with an experimental period of 4 weeks. Before conducting the experimental teaching, the teachers participating in the experimental teaching were trained and gave their opinions on the STEM lesson plan on the topic of energy conversion - making "Rotating Lantern" that we designed.

The results obtained from the experiment were analyzed using IBM SPSS software to determine whether there were any statistically significant differences between the problem-solving skills of the students in the experimental and control groups.

Building Criteria-Based Measurement Tools

We began by reviewing the Programme for International Student Assessment (PISA) frameworks on the constructs of students' problem-solving abilities and studying the requirements of secondary school students in STEM learning by the Vietnamese Ministry of Education and Training. This document also serves as a theoretical basis for determining the constructs and levels of students' problem-solving skills, while building a measurement tool according to the criteria of this study. For each identified construct, we searched for scales appropriate for the context of STEM teaching in secondary schools.

We developed a questionnaire on the number of criteria, described it in detail, and then used the Delphi method to standardize the measurement table based on the criteria (Table 1). The answers of the experts through three rounds of consultation were calculated on a 5-level Likert scale: (1) completely unsuitable, (2) unsuitable, (3) relatively suitable, (4) suitable, and (5) completely suitable. Experts were consulted by sending questionnaires and collecting results using Google Forms. The total number of questionnaires collected was 314, and after the data cleaning process (removing questionnaires with only one answer option; questionnaires with answers according to the rules), 263 official questionnaires (83.8%) were used. After synthesizing the expert opinions, we reviewed and edited the content of the criteria to suit the research purpose (Table 1).

Table 1. *Cronbach's Alpha Reliability of the Assessment Criteria Table*

Agents	Problem Solving Skills	Criteria	Indexes	Item-Total Correlation Coefficient	Cronbach's Alpha Coefficient
Concrete Experience	Understanding the Problem (S1)	Analyze the context from Concrete Experience to understand the problem	ConE_1.1 ConE _1.2 ConE _1.3	0,611 – 0,995	0,963
		Preliminary Identification of the Problem to be Solved	ConE _2.1 ConE _2.2 ConE _2.3		
Reflective Observation	Analysis and Connecting Knowledge (S2)	Linking STEM Subject Knowledge	ReO_1.1 ReO_1.2 ReO _1.3	0,837 – 0,988	0,975
		Building Theoretical Models (Initial Ideas for Solutions)	ReO_2.1 ReO_2.2 ReO 2.3		
Abstract Conceptualization	Proposed Solution to the Problem (S3)	Draw and interpret blueprints	AbC_1.1 AbC_1.2 AbC_1.3	0,644 – 0,973	0,899
		Choose a solution (blueprint)	AbC_2.1 AbC2.2 AbC_2.3		
Active Experimentation	Implement and evaluate the solution (S4)	Implement the solution (prototype)	AcE_1.1 AcE_1.2 AcE_1.3	0,754 – 0,972	0,959
		Test and refine the prototype	AcE_2.1 AcE_2.2 AcE_2.3		

The results of Cronbach's alpha analysis show that all scales in this study have high reliability, with Cronbach's alpha coefficients of the factors exceeding the threshold of 0.9. This proves that the scales have good internal consistency and ensure high reliability for Concrete Experience, Reflective Observation, Abstract Conceptualization, Active Experimentation. In addition, the total item correlation coefficients of the indicators in each factor have high values, showing that these indicators have a close relationship with the overall factor and contribute significantly to the structure of each scale.

FINDINGS/CONCLUSIONS

Student learning outcomes by experience stages

Activity 1: Concrete Experience

Figure 4.

Revolving Lantern

Students get hands-on experience with the Revolving Lantern model by observing and manipulating traditional lantern models (Figure 4). This activity involves watching videos or hands-on demonstrations of how the Revolving Lantern works, and feelings of energy conversion (heat from the candle creates movement and light). This stage provided students with a practica

l basis for approaching this problem and forming an initial awareness of energy conversion.

Activity 2. Observation and reflection

Figure 5.

Observation and reflection

After the hands-on experience, students analyzed and reflected on the observed phenomena. Teachers guide students to ask questions such as "Why can the Revolving Lantern rotate?", "How is the heat energy from the candle converted into mechanical energy and light energy?". Students discuss this in groups, record their observations and hypotheses, and make initial conclusions about energy transformation.

Activity 3. Abstract Conceptualization

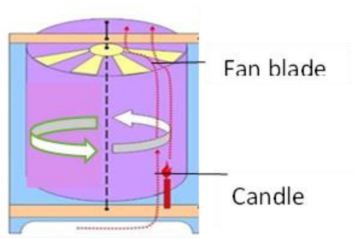

Figure 6.

Principle of rotational motion

Students were guided to connect observations to STEM knowledge. Teachers provide scientific concepts such as energy conversion (heat to mechanical and light energy), rotational motion, and the effects of various factors (lamp size, candle height, materials, Figure 6). This stage helps students build deeper scientific understanding and generalize what they have experienced

Activity 4. Positive test

Experience building a Revolving Lantern model and testing different designs (Figure 7).

Figure 7. *Fabrication of Revolving Lantern*

Activity 5. Active Experimentation

Students apply their knowledge to improve or create new revolving lanterns. Groups can make changes to the design, such as adjusting the size of the lantern, changing the type of candle, or using different materials to optimize the performance. This phase encouraged students to create, test, and adjust their products based on feedback and experimental results, thereby developing practical problem-solving skills.

Results Of Assessing Students' Problem-Solving Skills

Results of the experimental group of students

According to Cleveland and McGill (1985), radar charts are an effective data visualization method when users need to evaluate the overall comparison rather than focus on individual criteria. This is suitable for STEM education studies, where students' abilities must be compared in many aspects such as problem-solving skills, design, empathy, and STEM lesson products. Radar charts provide a visual view of the data, helping analysts to easily identify trends and anomalies (CRM, 2022). Radar charts display multiple criteria simultaneously so that viewers can visually compare and analyze them (Friendly 2008). The criteria were arranged in a concentric axis form, allowing for a correlation assessment between them and identifying the strengths and weaknesses of each subject (Nagy & Bokor, 2007). Clearly identify the criteria for improvement, helping optimize teaching and learning methods (Jüttler et al., 2019). The radar chart is suitable for assessing the improvement of students' skills Experimental group (E- Group) and Control group (C- Group) participating in the experimental model Kolb's experiential learning model in STEM education. We randomly selected a group of 4 students in the experimental sample to examine how the Kolb's experiential learning model in STEM education affects the problem-solving skills of high school students (see chart Figure 8)

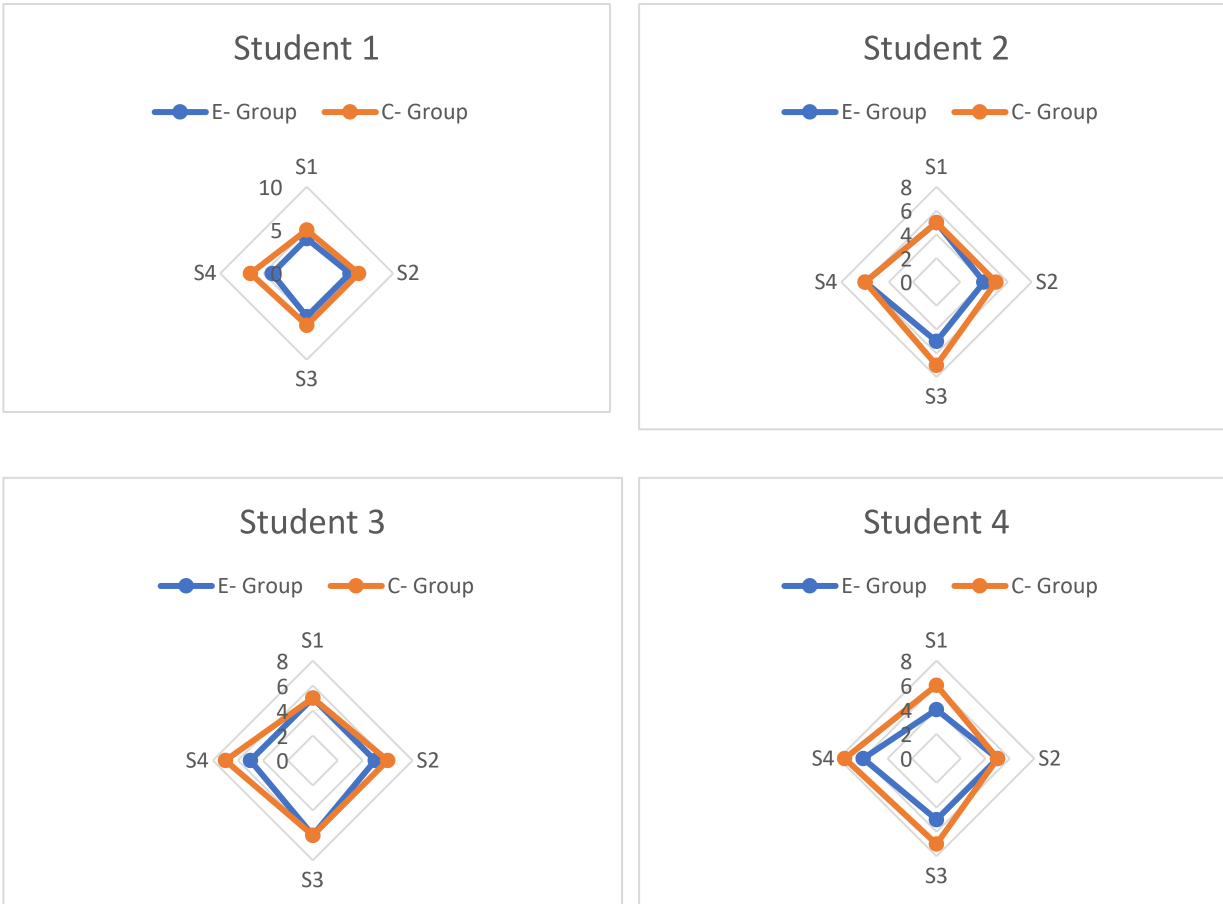

Figure 8. *Graph showing students' skills (E- group and C- group)*

RQ1: The radar chart compares problem-solving skills (S1, S2, S3, and S4) of students in the experimental (E group) and control (C group) groups. Using the area of the radar chart provides a quantitative approach for evaluating the overall skill improvement and balance across skills. Analysis of the Rada chart area (Figure 8) showed that the experimental group (Group E) had an area of: 49.93 (relative units). A larger area reflects a higher overall level of problem-solving skills, with balanced development across all skills (S1-S4). This shows that the students in Group E achieved significant improvement through the experiential learning method based on Kolb's model.

Regarding the consistency of all skills, demonstrating the effectiveness of integrating practical and reflective activities in STEM education, the control group (Group C) had an area of: 23.78 (relative units). A smaller area represents a lower level of problem-solving skills, with significant differences between the skills. Traditional teaching methods contribute to uneven skill development, especially for higher-order skills such as S3 and S4. Area difference: 26.15 (relative units). The significant increase in the E-group area reflects the comprehensive development of problem-solving skills. This is consistent with the pedagogical goals of Kolb's experiential learning model, which emphasizes a cyclical learning approach. These results emphasize the importance of engaging students in hands-on, reflective, and practical STEM activities to promote comprehensive and balanced skill acquisition.

The radar chart area analysis shows the transformative impact of experiential learning in STEM education. The E-Group not only scored higher in all skills, but also demonstrated a balanced and integrated growth trajectory. This emphasizes the need to shift from traditional methods to experiential approaches to foster creative problem-solving skills among middle school students.

The graph in Figure 8 shows that there was a statistically significant difference between the students' problem-solving skills in the real and control classes. Specifically, Skill S1 (Understanding the Problem): The experimental class (S1-E) had a higher average score than the control class, reflecting students' ability to identify and understand the problem. Experiential activities, such as direct observation of the lantern and group discussions, helped students gain a deeper understanding of the problem to be solved. The stability of the scores showed that most students achieved a similar level of understanding with the support of the experiential teaching method. The control class (S1-C) had a lower score and was more dispersed than the experimental class, showing the limitations of traditional teaching methods in helping students identify and understand the problem correctly.

Skill S2 (Analyze and Connect Knowledge): Experimental class (S2-E). Students in the experimental class scored significantly higher, reflecting their ability to analyze elements related to the problem and connect knowledge from STEM fields, such as physics (energy conversion) and engineering (construction of the carousel). Reflective discussion and analysis of the working principle of the carousel helped the students develop this skill. The control class (S2-C), which scored lower, showed that the students had difficulty analyzing and connecting knowledge. This may be due to a lack of hands-on activities or opportunities for students to apply their knowledge to real-world situations. Skill S3 (Proposing Solutions to Problem Solving). The experimental class (S3-E), which scored significantly higher than the control group, demonstrated an ability to propose creative and feasible solutions to problems. Students used their analytical knowledge from S2 to propose improvements to the carousel design, such as changing the materials or structures to increase rotation efficiency. Experiential activities encouraged the students to experiment with different ideas, which facilitated the

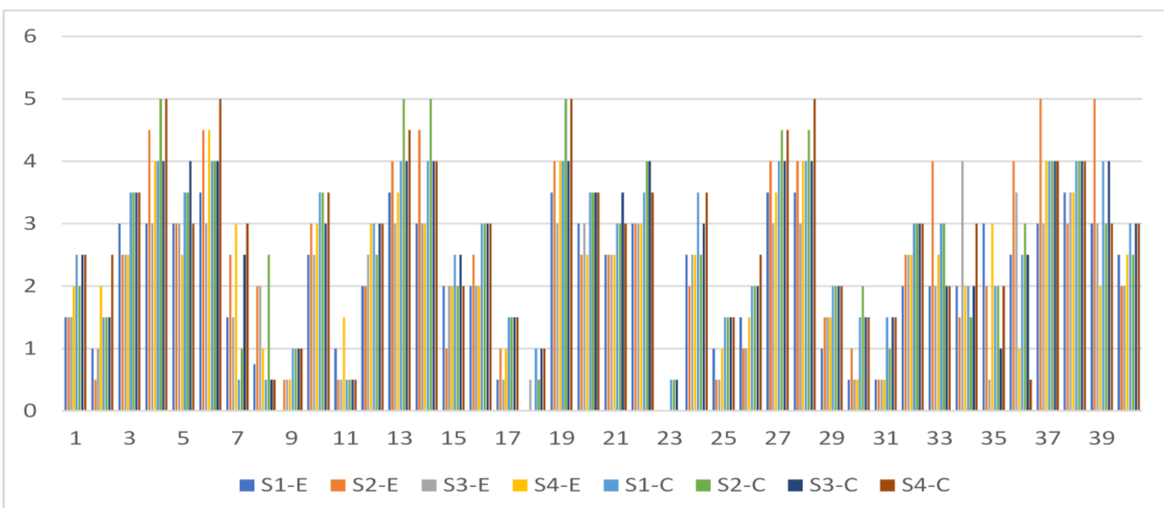

Figure 9.

Problem - solving skills of students in the control class and the experimental class

development of this skill. The control class (S3-C), which scored lower and more diffusely, demonstrated a deficit in their ability to propose solutions. Students may have difficulty translating theory into practical ideas.

Skill S4 (Implementation and Evaluation of Solutions). The experimental class (S4-E), which scored the highest in experiential learning, reflected the ability to implement the proposed solutions and evaluate their effectiveness. The students built, tested, and adjusted the carousel model. This process helped students develop critical thinking skills and the ability to optimize their solutions. The control class (S4-C), which scored lower, showed that students had fewer opportunities to practice and evaluate the solutions. This limits their ability to apply their knowledge in practice.

The overall comparison between the two classes showed that the experimental class scored higher on all four skills, especially S3 and S4. This demonstrated that the experiential learning method not only helped students understand the problem, but also developed the ability to analyze, propose solutions, and implement ideas effectively. The control class had lower scores on all skills, with a significant difference between S3 and S4. This indicates that it is difficult for traditional teaching methods to fully develop students' problem-solving skills.

RQ3: To assess the students' overall problem-solving abilities, we assessed the three levels and compared the ability levels achieved in the control and experimental classes. The three ability levels corresponded to three score levels: Level 1. Scores ranged from 0 to 4.75, level 2. Scores from 5 to 7, Level 3. Scores from 8 points. The scores were then statistically calculated as percentages and are presented in Figure 9.

Figure 10 shows that there was a difference in the learning outcomes between the control and experimental groups. At Level 1,52.5% of students met the standard; in the control class, it was 25% lower than in the experimental class (27.5%). At Level 2, the control class had 35.5% of students meeting the standard, and the experimental class had 42%. The assessment results of level 3 were significantly different from those of levels 1 and 2, with respective rates of 12.5% and 30%. This shows that learning STEM through experience is more effective than teaching using traditional methods.

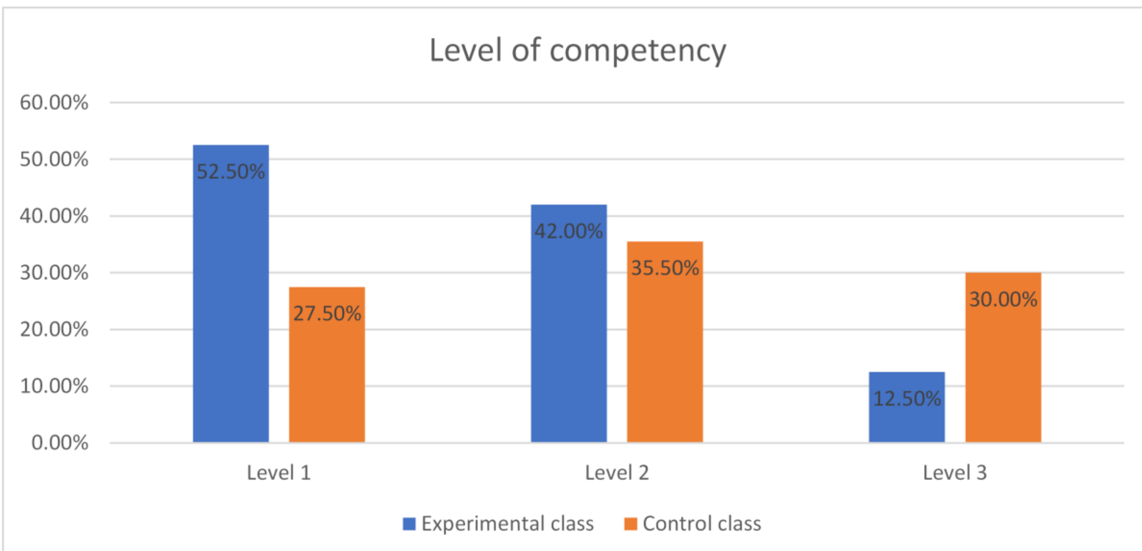

Figure 10.

Competency level of students in control class and experimental class

Table 2. *Reliability of the scale scores of the experimental and control classes. Item-Total Statistics*

Skill	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
S1-E	6,71	14,114	,899	,933
S2-E	6,48	11,628	,911	,930
S3-E	6,80	14,715	,835	,950
S4-E	6,56	12,361	,917	,924
S1-C	8,14	13,846	,942	,949
S2-C	8,05	13,151	,899	,961
S3-C	8,12	13,869	,943	,949
S4-C	8,05	12,921	,895	,963

The reliability of the skill scale using the scores of the experimental class (E) and the control class (C) was assessed based on Cronbach's alpha coefficient (Table 2), showing high homogeneity and reliability in the measurement items of both groups, the experimental class, and the control class. Specifically, the overall Cronbach's alpha coefficient of the scale in the experimental class was 0.950, indicating a high level of reliability. Each item in the scale had a total item correlation coefficient greater than 0.8, demonstrating that these items had high homogeneity. If any item is removed, Cronbach's alpha coefficient will decrease or not change significantly, demonstrating that these items are necessary and suitable for the scale.

Similarly, the scale in the control class achieved a high overall Cronbach's alpha coefficient of 0.966. The item-total correlation coefficients of each item were all above 0.89, confirming that the items in the scale were closely linked and reflected the measured aspects. Removing any item did not improve the overall Cronbach's alpha coefficient, demonstrating the reasonableness and necessity of items in the scale structure.

Để kiểm tra mối quan hệ giữa các giai đoạn của Kolb's ELM và các yếu tố ảnh hưởng đến kỹ năng giải quyết vấn đề của học sinh, chúng tôi đã sử dụng phần mềm IBM SPSS để phân tích mối tương quan Pearson (xem Bảng 3).

Bảng 3. ***Pearson correlation analysis results***

PT_Lock			Understanding the Problem (S1)	Analysis and Connecting Knowledge (S2)	Proposed Solution to the Problem (S3)	Implement and evaluate the solution (S4)
PT_Lock	Pearson Correlation	1	,410**	,318**	,421**	,349**
	Sig. (2-tailed)		,000	,000	,000	,000
	N 334	334	334	334	334	334
Concrete Experience	Pearson Correlation	,440**	1	-,031	,093	-,071
	Sig. (2-tailed)	,000		,632	,140	,179
	N 334	334	334	334	334	334
Concrete Experience	Pearson Correlation	,340**	-,041	1	-,032	,014
	Sig. (2-tailed)	,000	,610		,467	,724
	N 334	334	334	334	334	334
Abstract Conceptualization	Pearson Correlation	,451**	,089	-,043	1	,032
	Sig. (2-tailed)	,000	,130	,457		,528
	N 334	334	334	334	334	334
Abstract Conceptualization	Pearson Correlation	,379**	-,083	,016	,032	1
	Sig. (2-tailed)	,000	,187	,774	,538	
	N 334	334	334	334	334	334

RQ 3: Data analysis from Table 3 shows the relationship (impact) between Kolb's ELM and students' problem-solving skills:

Skill S1 (Understanding the problem): $r = 0.410$ ($p < 0.01$), average relationship statistically significant. S2 (Analyzing and connecting knowledge): $r = 0.318$ ($p < 0.01$), average relationship statistically significant. S3 (Proposing solutions): $r = 0.421$ ($p < 0.01$), an average relationship higher than S1 and S2. With S4 (implementing and evaluating solutions): $r = 0.349$ ($p < 0.01$), the average relationship. Meaning: Overall skill PT_Lock has a significant relationship with all stages of problem-solving, especially with the skill of proposing solutions (S3). This finding demonstrates the importance of developing reasoning and creativity.

The relationship between Concrete Experience and problem-solving skills: With S1 (understanding the problem): $r = 0.440$ ($p < 0.01$), a strong medium correlation. For S2 (Analyzing and connecting knowledge): $r = -0.031$ ($p = 0.632$), no significant correlation was observed. With S3 (posing solutions): $r = 0.093$ ($p = 0.140$), there was a weak, insignificant correlation. With S4 (implementing and evaluating solutions): $r = -0.071$ ($p = 0.179$), no significant correlation was observed. This shows that practical experience helps students understand problem (S1) but does not have a close relationship with higher stages, such as analyzing or proposing solutions. The reason may be that direct observation only helps with initial perception but is not enough to develop analytical and creative thinking.

Relationship between Reflective Observation and problem-solving skills: With S1 (Understanding the problem): $r = 0.340$ ($p < 0.01$), a moderate correlation. For S2 (Analyzing and connecting knowledge): $r = -0.041$ ($p = 0.610$), no significant correlation was observed. With S3 (posing solutions), $r = -0.032$, no significant correlation was observed. With S4 (implementing and evaluating solutions): $r = 0.014$ ($p = 0.724$), no significant correlation was observed. Meaning: Direct observation helps students understand problem (S1) but does not significantly contribute to the steps of proposing or implementing solutions.

Relationship between Abstract Conceptualization and problem-solving skills: Skill S1 (Understanding the problem): $r = 0.451$ ($p < 0.01$), medium-strong correlation. Skill S2 (analyzing and connecting knowledge): $r =$

0.089 (p = 0.130), with no significant correlation. Skill S3 (Proposing solutions): r = −0.043 (p = 0.457), with no significant correlation. Skill S4 (Implementing and evaluating solutions): r = 0.032 (p = 0.528), no significant correlation. This relationship shows that abstraction helps to better understand the problem but does not directly affect the ability to analyze, propose, or implement solutions.

The relationship between Active Experimentation and problem-solving skills: Skill S1 (understanding the problem): r = 0.379 (p < 0.01), moderate correlation. Skill S2 (analyzing and connecting knowledge): r = −0.083 (p = 0.187), no significant correlation. Skill S3 (Proposing solutions): r = 0.016 (p = 0.774) with no significant correlation. Skill S4 (Implementing and evaluating solutions): r = 0.032 (p = 0.538), no significant correlation. This shows that active experimentation helps students understand the problem better, but does not significantly impact the skills of analyzing, proposing, or implementing solutions.

In general, the above results show that the use of experiential learning models needs to be combined with other teaching methods and forms to fully develop problem-solving skills.

Table 4. ***Results of confirmatory factor analysis (CFA)***

Factor	Estimate (Standardized Regression Weights)	ModelFit						CR	AVE	MSV	Square Root of AVE
		CMIN/df	*GFI*	*CFI*	*TLI*	*RMSEA*	*PCLOSE*				
DL_Unp	0,869 – 0,912							0,945	0,739	0,010	0,882
DL_CDig	0,840 – 0,887							0,937	0,750	0,008	0,866
DL_Ex	0,802 – 0,881	1,522	0,912	0,962	0,962	0,040	1,000	0,937	0,714	0,010	0,845
DL_Bmp	0,806 – 0,894							0,923	0,731	0,007	0,855
DL_Tes	0,868 – 0,877							0,947	0,786	0,008	0,886

RQ3: The results of the CFA (Table 4) show a high fit with the actual data, while ensuring the reliability and validity of the scale. CMIN/df (Chi-square/df): 1.522 (< 2), indicating that the model was not too complicated and fit the actual data. (Goodness-of-Fit Index): 0.923 (> 0.9), indicating a good fit between the model and data. The Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) both reached 0.962 (> 0.9), indicating that the theoretical model fit the empirical data very well. RMSEA (Root Mean Square Error of Approximation): 0.040 (< 0.05), indicating that the deviation between the theoretical model and the data was very small. Composite Reliability (CR): Average 0.919 (> 0.7), demonstrating the high reliability of the scale. Average Variance Extracted (AVE): From 0.739 to 0.786 (> 0.5), it has good convergence according to the criteria of Fornell and Larcker (1981), proving that the indicators in each factor measure the same concept. The GFI = 0.912 and AGFI = 0.908 indices both exceeded the threshold of 0.9, indicating good agreement between the theoretical model and the actual data, corresponding to the requirements of Schumacker and Lomax (2010).

Simultaneously, the CFI = 0.982 and TLI = 0.981 indices were both above 0.9, indicating that the model of the relationship between Kolb's ELM and problem-solving skills (Figure 1) was reliable. RMSEA = 0.020 and PCLOSE = 1.000 did not show a significant deviation in the model, achieving a good fit, according to the criteria of Hu and Bentler (1999). Regarding the composite reliability, the average CR reached 0.937, far exceeding the acceptance threshold of Nunnally and Bernstein (1994) of 0.7, demonstrating the high reliability of the scales.

CONCLUSION/ IMPLICATIONS

This study highlights the role of Kolb's Experiential Learning Model (ELM) in fostering problem-solving skills in STEM education. The findings confirm that Concrete Experience plays a crucial role in helping students understand problems, whereas Reflective Observation and Abstract Conceptualization contribute to deeper analysis and knowledge integration. However, Active Experimentation alone did not significantly enhance problem-solving skills, suggesting the need for structured guidance in this phase.

The study also reveals that traditional teaching methods result in uneven skill development, particularly in higher-order cognitive abilities such as proposing and evaluating solutions. In contrast, experiential learning promotes more balanced and comprehensive growth, reinforcing its relevance to competency-based STEM education.

In addition, the reliability and validity of the assessment framework were confirmed through statistical analysis, supporting the use of performance-based evaluation methods in experiential STEM learning. These findings advocate for a pedagogical shift towards hands-on, inquiry-driven instruction, aligning with modern educational reforms emphasizing critical thinking and real-world applications.

This study was conducted with 334 ninth-grade students from two middle schools. Although the results showed a positive impact of Kolb's experiential learning model (ELM) on problem-solving skills in STEM education, the study was not sufficiently large to confirm the generalizability of the results. The study only assessed changes in students' problem-solving skills over a four-week period, which is not sufficient to determine the long-term effectiveness of the experiential learning model in STEM education. Monitoring students' skill development over several months or school years would provide a better understanding of their level of knowledge retention and application in practice.

Ethical Statement

This study was conducted in strict compliance with the ethical principles of scientific research. All data and information collected were honest, transparent, and did not violate the privacy of any individual or organization. The study did not use human or animal subjects; therefore, approval from the ethics committee was not required.

We also declare that there are no conflicts of interest that could affect the results and processes of this study. All reference sources were fully and accurately cited according to the regulations.

Images and data were created from experimental research results, and their use was in accordance with Vietnamese law.

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