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Teaching STEM using the 5E model approach: Assessing problem-solving skills of middle school students

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Abstract

STEM education plays a critical role in developing students' problem-solving and critical thinking skills. The 5E instructional model has been widely implemented in science education but requires further empirical validation regarding its effectiveness in enhancing problem-solving abilities in secondary STEM education. This study examined the impact of the 5E instructional model on middle school students' problem-solving skills through an experiential STEM project, designing and constructing a life-saving buoy from recycled materials. A quasi-experimental design was applied to 240 ninth-grade students from two middle schools. The experimental group engaged in a 5E-based STEM activity, while the control group followed traditional teaching methods. Pre- and post-tests, classroom observations, and semi-structured interviews were conducted for data collection. Confirmatory Factor Analysis (CFA) and Pearson's correlation were used to assess skill development. This study proposes a model 5E in STEM education to help students develop critical thinking, creativity, and problem-solving skills. Empirical analysis confirmed the relevance of the model, emphasizing the role of iterations in STEM learning in optimizing solutions. The findings highlight the close connection between the different stages of Model 5E, reinforcing the importance of exploring learning in STEM education. Integrating the 5E instructional model into STEM education fosters critical thinking, creativity, and hands-on problem-solving. This study emphasizes the need for structured interventions to bridge the gaps between problem identification, prototype design, and evaluation, ensuring holistic STEM competency development.

Keywords: 5E model, CFA middle school students, Problem-solving skills, STEM education.

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1. Introduction and Theoretical Framework

Science, Technology, Engineering, and Mathematics (STEM) education is increasingly becoming an important trend in the global education system, helping students develop higher-order thinking skills, including critical thinking, creativity, and problem-solving skills [1]. STEM teaching not only focuses on providing scientific knowledge but also emphasizes the ability to apply knowledge in practice through practice-oriented learning activities and projects [2].

STEM education plays an important role in raising awareness and equipping students with practical skills for solving social problems. One effective teaching method is the use of the 5E model (Engage, Explore, Explain, Elaborate, and Evaluate). This model has proven to be effective in helping students develop critical thinking, creativity, and problem-solving skills [1]. When applied to STEM education, the 5E model not only helps students actively acquire scientific knowledge but also encourages them to apply that knowledge in practice to solve problems in daily life [3]. Students must research, analyze, and design appropriate solutions [4]. However, integrating the 5E model into STEM education to develop these skills still faces several challenges. Several studies have shown that many teachers remain confused about designing STEM lessons according to the 5E model, which prevents students from fully developing their creative thinking and problem-solving abilities [5, 6].

Several studies have shown that applying the 5E model to STEM teaching improves students' problem-solving abilities. For example, Holbrook and Rannikmae [5] found that learning activities based on the 5E model help students gain a deeper understanding of scientific concepts and develop logical thinking. In addition, Eymur [6] demonstrated that using the 5E model in STEM education helps students significantly improve their critical thinking and problem-solving skills. Empirical studies on the effectiveness of the 5E model in developing problem-solving skills in STEM teaching are limited. Therefore, this study aimed to assess the level of problem-solving skill development of middle school students when participating in a STEM project based on the 5E model by designing and manufacturing life buoys from recycled materials.
Specifically, this study focused on the following questions:

RQ1: How does the 5E model affect the development of students' problem-solving skills in STEM education?
RQ2: How do students demonstrate the stages of the 5E model when implementing the Lifebuoy Project?
RQ3: Is the 5E model suitable for STEM education in middle school?

1.1. 5E Teaching Model in Science Teaching

The 5E model is a teaching method based on constructivist theory, developed by Bybee and colleagues in the Biological Sciences Curriculum Study (BSCS). According to Bybee, et al. [7] this model encourages students to actively participate in the learning process and construct knowledge through practical experiences. The 5E model has become an effective approach to teaching science, encouraging students to participate in the learning process in an active and autonomous manner [7]. This model includes five main stages (Figure 1)

Engage Stage: This stage helps students connect existing knowledge with new concepts through activities that arouse curiosity and help them understand the problem. Teachers play the role of introducing situations or events that students cannot explain with their existing knowledge, thereby arousing interest and creating cognitive conflict, which is an important factor in forming students' need to learn and acquire new knowledge [8]. The interactive stage not only motivates but also helps students activate their previous knowledge, thereby enhancing their ability to absorb and process new information [9].

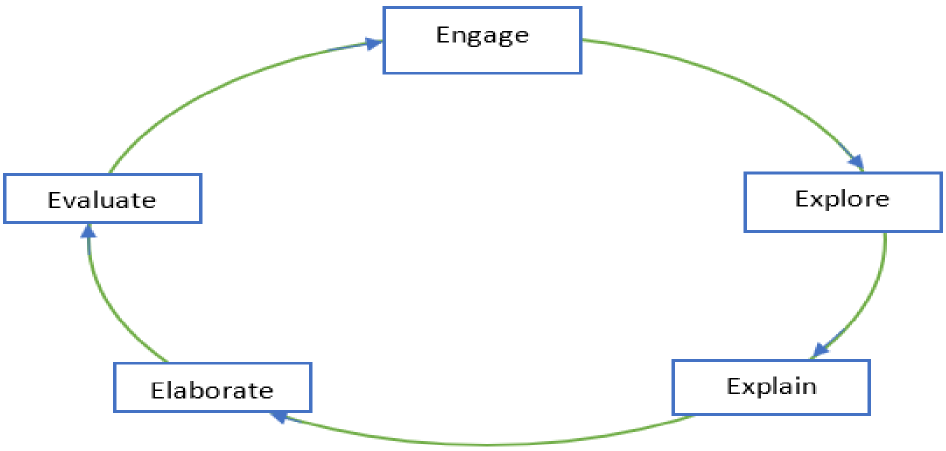

Figure 1.
5E model.
Source: Bybee [1].

In the Explore phase, students are encouraged to engage in activities that involve experimentation and the discovery of new knowledge. Teachers act as guides and facilitate students in exploring concepts through hands-on experiments and observations. According to Ruiz-Martín and Bybee [8] this phase provides students with the opportunity to make connections between prior and new knowledge through guided inquiry and discovery. Students not only retain knowledge more deeply but also develop thinking and problem-solving skills.

The explanation phase provides an opportunity for students to present and discuss what they have learned during their exploration. Teachers can introduce more precise concepts to help students organize and reorganize their knowledge. Students can also participate in explaining new concepts, helping them gain a deeper understanding and be able to accurately apply them to real-world situations.

In the Elaborate stage, students are challenged to apply their new knowledge to different situations, which helps to consolidate and expand their understanding. According to Gentner, et al. [10] applying knowledge in different contexts helps students gain a deeper understanding of concepts and develop the ability to apply them flexibly to new situations. The final stage (assessment) focuses not only on assessing learning outcomes but also encourages students to self-assess their learning process. The evaluation stage is not only a tool for measuring knowledge but also an important part of the learning process, helping to consolidate and improve the ability to remember knowledge long-term [11] finding incomplete elements, missing skills, self-development and perfect products, and personal capacity.

Bybee [1] found that students who followed the 5E model scored higher on tests of scientific understanding than those who followed the traditional method. Eymur [6] also found that the 5E model helps students develop better critical thinking when participating in STEM activities, especially in the field of chemistry. Capraro, et al. [3] found that when applying the 5E model to STEM project-based teaching, students demonstrated higher logical and creative thinking skills than those who followed the traditional teaching method. Holbrook and Rannikmae [5] suggested that the 5E model helps students feel more interested in science because they are directly involved in the discovery process instead of just passively receiving information. Sarı and Çelikler [12] conducted an experimental study and found that students who followed the 5E model were more motivated to learn, as this method allowed them to experience and apply knowledge to real-life situations. Kulo and Bodzin [13] applied the 5E model in teaching environmental science and found that students were able to enhance their ability to analyze problems and connect knowledge to real-life situations. Alozie, et al. [14] tested the 5E model in secondary school STEM classes and found significant improvements in students' ability to collaborate in groups and to solve problems.

Overall, previous studies have shown that the 5E model not only helps students improve their learning outcomes, but also supports the development of skills needed for the 21st century, especially in the context of STEM education. The stages of the 5E model not only encourage students to actively explore and discover but also help them develop critical thinking, problem-solving, and collaboration skills during the learning process [15]. This is consistent with the goal of STEM education, which is not only to teach theory, but also to help students apply knowledge to real-life situations [16]. However, more empirical studies with specific student populations are required to evaluate the effectiveness of this model in real-life teaching conditions.

1.2. 5E Model in STEM Education

Recent STEM learning model studies have attempted to build a science-teaching model that combines STEM learning. The 5E model of the research group, called the BSCS [7] has been applied in STEM education and science teaching at the elementary level. STEM lessons were designed in five stages: Engage, Explore, Explain, Elaborate, and Evaluate. There was no iterative process. The 5E model is problematic because it does not fully represent the design process [17]. Therefore, this model has been studied and improved in the 6E model, but the 6E model does not focus on the problem-solving process. According to the 6E model, students are free to create simple prototypes with the main purpose of creating interest in scientific exploration. This study proposed a STEM teaching model that approaches the 5E process (Figure 2).

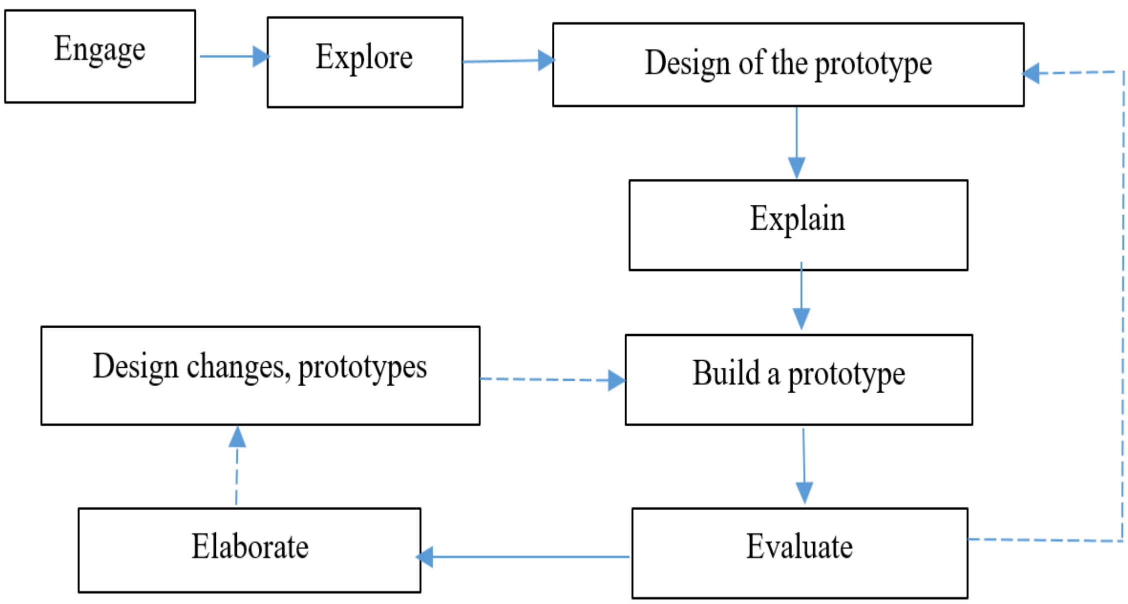

Figure 2.
5E model in STEM education based on the model.
Source: Bybee [1]

Engage Stage: The goal of this stage is to help students get into a learning mindset and pay attention to the lesson. Students are placed in challenging situations, events, or problems related to learning content that stimulates cognitive needs.

In essence, this is about creating problematic situations that make students think: Why could that happen? I have thought about this, but do not know how to explain it? This stage helps students explore and discover the problems they need to solve under the guidance of the teacher [18]. Students' active questioning is the first step in developing critical thinking because they learn to analyze and evaluate initial information to find a direction for the discovery process [19].

Explore Stage: At this stage, learners experience the exploration and discovery of knowledge through learning activities, such as collecting data, observing models, experiments, and investigations to explain phenomena and develop their own cognitive abilities. Direct participation in experimental activities not only helps students develop practical scientific skills but also encourages them to develop observation, data collection, and analytical skills [20].

Explain Phase: Based on the results of the exploration phase, students analyze and interpret data, and discuss knowledge, and possible solutions. In STEM learning, students draw and explain the design of the prototype. This is an opportunity for them to learn how to present and defend their views, thereby forming critical scientific thinking skills [21]. Furthermore, students' self-explanation and criticism of different perspectives help improve their problem-solving skills by analyzing different options and choosing the optimal solution [14].

Elaborate Stage: This stage is where students learn to apply theory to practice, practicing their decision-making skills based on the scientific evidence they have collected [21]. Students expand their knowledge by applying what they have learned to new situations and contexts. At this stage, students are encouraged to create and improve the solutions they have proposed, which helps them expand their creative thinking and problem-solving abilities in complex situations [18]. Students refine solutions, designs, and prototypes, and test them to expand and connect STEM knowledge to practice, which is an important skill in the STEM learning process.

Evaluation phase: The evaluation is conducted through the content of the learner's presentation of the solution to the initially posed problem. During this phase, students are involved in peer evaluation, and teachers evaluate both the students' designs and prototypes and consider design explanations that demonstrate their understanding of STEM knowledge. This process helps students develop self-directed and self-regulated learning skills. It also provides an opportunity for teachers to evaluate students' abilities based on their ability to explain, practice, and apply scientific knowledge [19]. Self-evaluation helps students develop critical thinking skills, as they review their entire learning process, recognize what they do well, and understand what needs improvement [7].

In this study, the 5E model in STEM education consisted of seven steps (Figure 2) and could be used in an iterative manner (dashed arrow). Lesson-related knowledge research activities can be organized and performed concurrently with solution proposals, whereas prototyping activities can be performed concurrently with testing and evaluation. One step involves both the goal and the condition for performing the other. The iterative process helps students understand that failure is not a negative thing, but an opportunity to learn and improve. Each failure in testing the prototype is a step towards identifying a more accurate solution [22].

2. Research Design and Methods

2.1. Background

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

In terms of theoretical research, a STEM teaching process suitable for research purposes was developed (Figure 2). We 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 the theoretical research results for research purposes and teaching practice in general schools. An experimental design was used to test the development of students' problem-solving skills and to demonstrate the effectiveness of STEM teaching using the 5E model approach. The sample was selected from 240 grade 9 students from two middle schools who voluntarily participated in the experimental study.

2.2. Build a Criteria-Based Measurement Tool

First, we reviewed the PISA 2012 framework to assess problem-solving abilities. This document provides a theoretical basis for identifying the constructs and levels of students' ability to build measurement tools according to the criteria in this study. For each identified construct, we searched for scales suitable for STEM learning using the 5E model approach. We developed a questionnaire to collect expert opinions (Delphi method), which included three questions on the problem-solving ability construct. Each question was divided into three parts (i.e., the three assessment criteria for each component). The expert responses over the three rounds of opinion collection were scored on a 5-point Likert scale: (1) not at all relevant, (2) not relevant, (3) somewhat relevant, (4) relevant, and (5) fully relevant.

Expert opinions were collected by sending out questionnaires and gathering results on Google Forms. The total number of questionnaires collected was 214, and after the data cleaning process (removing questionnaires with only one answer option; questionnaires with answers according to rules...), the number of official questionnaires used was 163 (accounting for 76.2%). After synthesizing expert opinions, we reviewed and edited the content of the criteria to align with STEM teaching objectives (Table 1).

Table 1.
Criteria for assessing students' skills after standardization.

Criteria code	Skill	Description	Maximum Score
S1	Understanding the problem	Students identify the user needs or real-world problems to be solved through observation and insight.	5
		Students analyzed the context and real-world conditions that influence the problem to be solved.	5
S2	Design of the prototype	Students come up with many creative ideas that are not limited by the usual barriers in the process of finding solutions.	5
		Students learn how to apply scientific and engineering knowledge to develop creative solutions.	5
S3	Explain	The design is presented clearly and scientifically, with harmonious colors and a list of the materials used.	5
		The design is explained, stating the operating principle of the manufactured product.	5
S4	Build a prototype	The model was assembled according to the correct principles, ensuring firmness and neatness. The prototype operates stably and meets technical requirements.	5
		The model has improvements and creative applications compared to basic designs. Ensure safety during operation, including power sources and materials.	5
S5	Evaluate	Conduct prototype testing and make adjustments to optimize efficiency.	5
		Students can self-test the prototype based on the given criteria and evaluate the problem-solving abilities of the solution.	5

To confirm the reliability of the scale, we used IBM SPSS software to analyze Cronbach's alpha coefficient to obtain standardized results (Table 2). The set of criteria (Table 1) was used to evaluate students' skills when conducting experimental teaching on the STEM lesson topic: making "Life Buoys from easy-to-find materials."

Table 2.
Assessment of scale reliability.

Factor	Criterion	Index	Item-total correlation coefficient	Cronbach's alpha coefficient
Understanding the problem	Students identify the user needs or real-world problems to be solved through observation and insight.	Undp_1.1 Undp_1.2 Undp_1.3	0.611 – 0.995	0.963
	Students analyzed the context and real-world conditions that influence the problem to be solved.	Undpp_2.1 Undp_2.2 Undp_2.3		
Design of the prototype	Students come up with many creative ideas that are not limited by the usual barriers in the process of finding solutions.	Dp _1.1 Dp _1.2 Dp_ 1.3	0.837 – 0.988	0.975
	Students learn how to apply scientific and engineering knowledge to develop creative solutions.	Dp_2.1 Dp_ 2.2 Dp- 2.3		
Explain	The design is presented clearly and scientifically, with harmonious colors and a list of the materials used.	Ex _1.1 Ex _1.2 Ex _1.3	0.644 – 0.973	0.899
	The design is explained, stating the operating principle of the manufactured product.	Ex _2.1 Ex _2.2 Ex_2.3		
Build a prototype	The model was assembled according to the correct principles, ensuring firmness and neatness. The prototype operates stably and meets technical requirements.	Bp_1.1 Bp_1.2 Bp_1.3	0.754 – 0.972	0.959
	The model has improvements or creative applications compared to basic designs. Ensure safety during operation, including power sources and materials.	Bp_2.1 Bp_2.2 Bp_2.3		

Factor	Criterion	Index	Item-total correlation coefficient	Cronbach's alpha coefficient
Evaluate	Conduct prototype testing and make adjustments to optimize efficiency.	Ev_1.1 Ev_1.2 Ev_1.3	0.603 – 0.795	0.890
	Students can self-test the prototype based on the given criteria and evaluate the problem-solving abilities of the solution.	Ev_2.1 Ev_2.2 Ev_2.3		

The results of Cronbach's alpha analysis show that all scales in the 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 the factors: Understanding the problem, Designing the prototype, Explaining, Building a prototype, and Evaluating. 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. Furthermore, all 10 indicators in the five criteria had total item correlation coefficients greater than 0.3, and the Cronbach's alpha indices if the variable was removed were smaller than the total Cronbach's alpha.

3. Research Results and Discussion

3.1. Student learning products

Learning topic: Making a "Lifebuoy from easy-to-find materials"

Background: Waterway accidents are becoming an alarming problem in many countries, especially in areas with dense river systems where small boats are used as a means of transport. Every year, many tragic cases occur because of a lack of safety equipment when traveling on boats, according to the World Health Organization. In Vietnam, this situation is even more worrying, as many students travel by boat to school without suitable rescue equipment. To minimize the damage caused by the lack of safety equipment on small boats, students apply knowledge of Archimedes' buoyancy and object buoyancy to design and manufacture an economical and environmentally friendly lifebuoy to support students in flood-affected areas who must travel by boat.

Objectives: To understand the problem and task to be solved, conduct experiments to investigate the effect of liquid on objects placed in liquid, present qualitative conditions for floating and sinking objects, and Archimedes' law. Propose ideas for designing a lifebuoy, calculate and draw a detailed design of a lifebuoy according to the requirements, and manufacture a lifebuoy according to the design.

Students Learning Products

Students conduct experiments, propose solutions (draw blueprints and explain them).

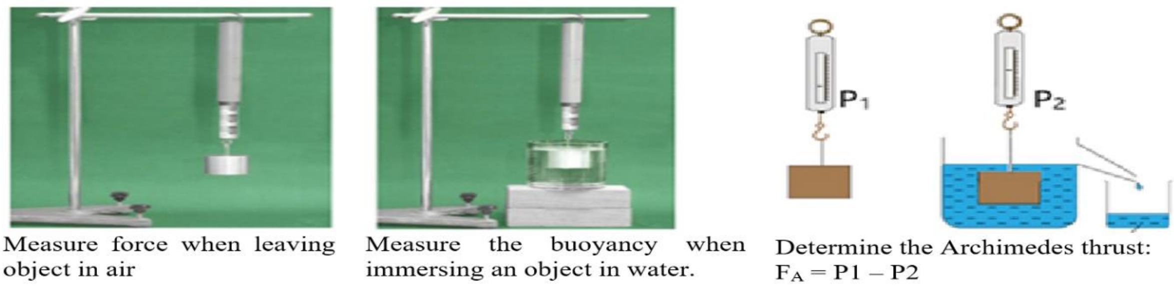

Figure 3.
Explore and explain.

Student groups build prototypes, test, and evaluate

Figure 4.
Build a prototype, evaluate and elaborate.

3.2. Analysis of Student Learning Outcomes

According to Cleveland and McGill [23] 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 need to be compared in many aspects, such as problem-solving skills and STEM lesson products. Radar charts provide a visual view of the data, helping analysts easily identify trends and anomalies [24]. Radar charts display multiple criteria simultaneously so that viewers can visually compare and analyze them [25]. The criteria are arranged in the form of concentric axes, allowing for a correlation assessment between them and identifying strengths and weaknesses in each subject [26]. Clearly identify the criteria for improvement, helping optimize teaching and learning methods [27]. Radar charts are suitable for assessing students' skill improvement before (pre-test) and after (post-test) participating in the 5E model trial [28].

We randomly selected a group of six students from the experimental sample to examine the impact of the 5E model on middle school students' problem-solving skills in STEM learning (see Figure 5).

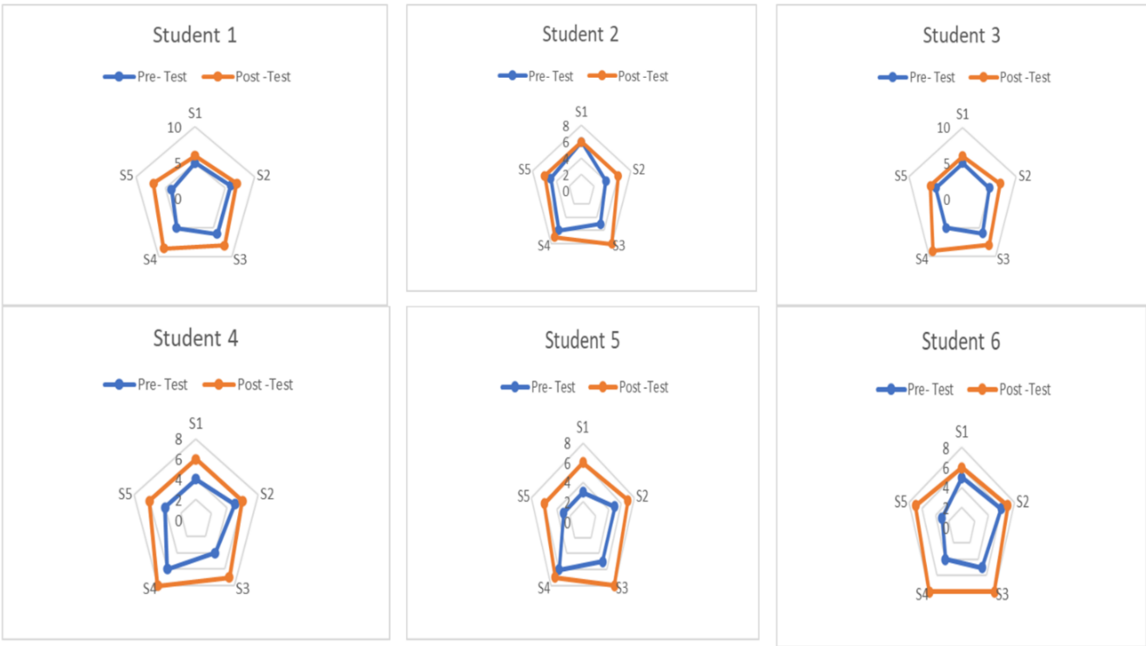

Figure 5.
Graph showing the skills of student groups (Pre-Test, Post-Test).

RQ1: Radar chart area analysis shows: Pre-Test Area: 23.78 (relative area units). Post-Test Area: 49.93 (relative area units). The area difference (Post-Test - Pre-Test) was 26.15 (relative area units). The Pre-Test has a smaller area, indicating that students before participating in the experimental program had uneven skill completion levels in all criteria. The Post-Test: The area increased significantly, showing even and strong improvement in all criteria. The larger post-test area shows that students achieved a higher level of proficiency, with skills developed synchronously. The increase in the area of 26.15 units clearly reflects the effectiveness of the 5E model teaching method. This demonstrates that students not only improved their individual skills but also had overall development in problem-solving. The larger area (post-test) not only reflects the improvement in skills but also shows that the criteria have achieved a more balanced and even level after the learning process according to the 5E model. The area-based method provides a visual view of the overall level of progress and helps comprehensively evaluate the effectiveness of the test.

RQ2: Skill S1 (Understanding the Problem) improved by 33.33%. In other words, students have made significant progress in analyzing real-world problems and identifying the problem to be solved. Skill Design of the Prototype (S2) improved by 25.00%. This skill increased significantly, but the increase was moderate compared with the other criteria. The skill Plan (S3) improved by 50.00%. This was the criterion with the most significant progress. Students moved from a very limited design ability to an excellent one. Skill Build a Prototype (S4) improved by 30.13%. There were significant improvements in the ability to practice and deploy the creation of prototype products. Skill Evaluate (S5) improved by 25.00%. Students improved their ability to test and evaluate products well; however, the increase was not too high because the previous foundation was quite good.

Figure 6 shows the improvement level (as a percentage) for each criterion after participating in the pilot program.

To examine the relationship between the stages of the 5E model and the factors affecting students' problem-solving skills, we used IBM SPSS software to analyze the Pearson correlation (see Table 3).

Table 3.
Results of Pearson correlation analysis.

PT_Lock			Understanding the problem	Design of the prototype	Explain	Build a prototype	Evaluate
PT_Lock	Pearson Correlation	1	0.440**	0.350**	0.451**	0.379**	0.537**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	N 240	240	240	240	240	240	334
Understanding the problem	Pearson Correlation	0.440**	1	-0.031	0.093	-0.083	0.039
	Sig. (2-tailed)	0.000		0.632	0.150	0.199	0.479
	N 240	240	240	240	240	240	334
Design of the prototype	Pearson Correlation	0.350**	-0.031	1	-0.046	0.018	0.076
	Sig. (2-tailed)	0.000	0.632		0.477	0.784	0.165
	N 240	240	240	240	240	240	334
Explain	Pearson Correlation	0.451**	0.093	-0.046	1	0.037	0.030
	Sig. (2-tailed)	0.000	0.150	0.477		0.568	0.583
	N 240	240	240	240	240	240	334
Build a prototype	Pearson Correlation	0.379**	-0.083	0.018	0.037	1	-0.006
	Sig. (2-tailed)	0.000	0.199	0.784	0.568		0.914
	N 240	240	240	240	240	240	334
Evaluate	Pearson Correlation	0.482**	0.031	0.092	0.074	0.001	1
	Sig. (2-tailed)	0.000	0.632	0.157	0.252	0.984	
	N 240	240	240	240	240	240	334

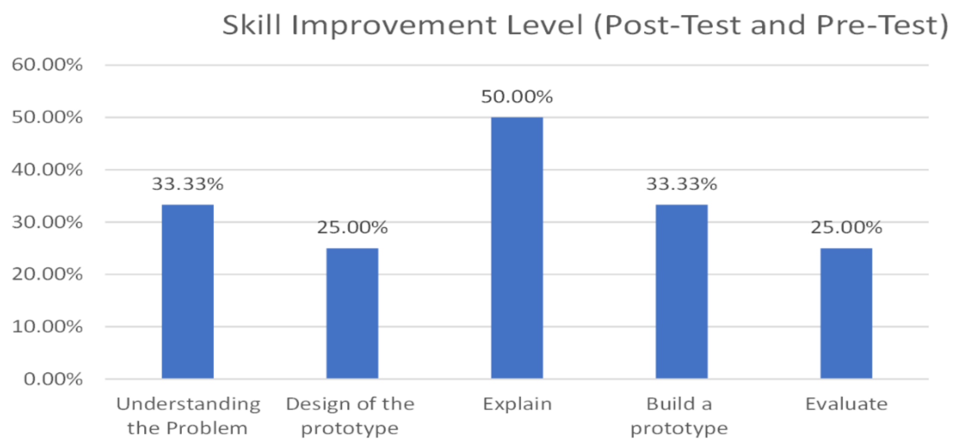

Figure 6.
Skill improvement as a percentage.

RQ 2: Pearson correlation analysis (Table 3) revealed that while students' overall learning progress increased their problem-solving abilities, there were important gaps between the stages of problem-solving. Specifically, understanding a problem did not automatically lead to strong design or construction skills, and students had difficulty transitioning between explaining, building, and evaluating prototypes. These insights suggest the need for structured interventions to bridge the gaps in experiential STEM education. Students' overall learning progress (PT_Lock) was positively correlated with all stages of problem-solving. The strongest correlation was observed with Evaluate ($r = 0.537$), suggesting that students who had made more progress in their learning also evaluated the solutions better. The explanation ($r = 0.451$) also had a strong correlation, indicating that students who understood the problem well tended to explain their prototype design more effectively.

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

Factor	Estimate (Standardized Regression Weights)	Model Fit						CR	AVE	MSV	Square Root of AVE
		CMIN/df	*GFI*	*CFI*	*TLI*	*RMSEA*	*PCLOSE*				
DL_Unp	0.869 – 0.912	1.131	0.922	0.992	0.991	0.023	1.000	0.955	0.778	0.010	0.882
DL_CDig	0.840 – 0.887							0.947	0.750	0.008	0.866
DL_Ex	0.802 – 0.881							0.937	0.714	0.010	0.845
DL_Bmp	0.806 – 0.894							0.942	0.731	0.007	0.855
DL_Tes	0.868 – 0.877							0.957	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): 1.133 (< 2), indicating that the model was not too complicated and fit the actual data. (Goodness-of-Fit Index): 0.922 (> 0.9), indicating a good fit between the model and data. The Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) both reached 0.994 (> 0.9), indicating that the theoretical model fit the empirical data very well. RMSEA (Root Mean Square Error of Approximation): 0.020 (< 0.05), indicating that the deviation between the theoretical model and the data was very small. Composite Reliability (CR): Average 0.949 (> 0.7), demonstrating the high reliability of the scale. Average Variance Extracted (AVE): From 0.739 to 0.785 (> 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 = 0.922 and AGFI = 0.908 indices both exceed 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).

At the same time, the CFI = 0.994 and TLI = 0.994 indices were both above 0.9, indicating that the 5E model for STEM education (Figure 2) 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 0.949, far exceeding the acceptance threshold of Nunnally and Bernstein (1994) of 0.7, demonstrating the high reliability of the scales.

4. Conclusion and Recommendations

The 5E model provides a clear process from problem identification, idea generation, design, implementation, to evaluation and extension, helping students learn in a real-world context. Adding specific steps to the model helped enhance the students' creativity and problem-solving abilities in STEM learning. All skills were developed equally, reflecting the students' comprehensive progress when participating in the pilot program. The correlation coefficient between S3 and S4 skills was 0.451 (p < 0.001), indicating a strong and statistically significant link. This shows that when students' design skills improve, their S4 skills are also enhanced, and a detailed and accurate design will help the implementation process proceed smoothly, minimizing errors. Students with good design skills often find it easier to handle practical problems during manufacturing. The link between S3 and S4 helps students understand the process of transforming ideas into real products. Encourage students not only to be creative in design but also to validate ideas through hands-on prototyping.

Limitations of the Study: The study was conducted on a sample of students in two middle schools, with a total of 240 students. The limitation of this study is that the sample size was not large or diverse enough to represent all STEM education contexts. This study focused primarily on the results before and immediately after the pilot program was implemented. This study did not assess the long-term effectiveness of the 5E model in the development of students' skills in learning contexts.

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