Development of Learning Activities using Engineering Design Process within STEM Education Framework to Enhance Grade 7 Students' Creative Problem-Solving Ability

OPEN ACCESS

Manuscript ID:
EDU-2025-14019522

Volume: 14

Issue: 1

Month: December

Year: 2025

P-ISSN: 2320-2653

E-ISSN: 2582-1334

Received: 06.09.2025

Accepted: 12.10.2025

Published Online: 01.12.2025

Citation:
Hinon, R., & Polyiem, T. (2025). Development of Learning Activities using Engineering Design Process within STEM Education Framework to Enhance Grade 7 Students' Creative Problem-Solving Ability. *Shanlax International Journal of Education, 14*(1), 93–102.

DOI:
https://doi.org/10.34293/education.v14i1.9522

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Abstract
The purposes of the present study were: (1) to develop learning activities using the engineering design process within the STEM education framework on the topic of Thermal Energy for Grade 7 students with a target efficiency of 75/75; (2) to compare students' creative problem-solving abilities before and after learning through the designed activities; and (3) to compare students' learning achievement before and after learning through the designed activities. The cluster random sampling technique was employed to select 39 Grade 7/12 students studying in the second semester of the 2024 academic year at Prasatwitthayakarn School in Surin Province. The research instruments included: (1) lesson plans based on the engineering design process and STEM framework, (2) a creative problem-solving ability test, and (3) a science achievement test developed by the researcher. Percentage, mean, and standard deviation were used to analyze the data, while the hypotheses were tested using E1/E2 efficiency analysis and the dependent samples t-test. The results revealed that (1) the developed learning activities achieved an efficiency of 82.53/80.07, (2) students' post-test creative problem-solving ability scores were significantly higher than their pre-test scores at the .05 level, and (3) students' post-test learning achievement scores were also significantly higher than their pre-test scores at the .05 level. These findings suggest that integrating the engineering design process within the STEM education framework is an effective instructional approach for enhancing both creative problem-solving ability and science achievement in secondary school students. Future research in this field could explore how integrating the engineering design process with STEM education influences other 21st-century competencies such as collaboration, critical thinking, and innovation—across diverse learning contexts.

Keywords: Learning Activities, Engineering Design Process, STEM Education, Creative Problem-Solving Ability, Thermal Energy

Introduction

Creative problem-solving (CPS) is a concept and approach developed in order to help problem solvers in using creative thinking to achieve their goals successfully. It enables individuals to overcome obstacles they face and promotes positive behaviors that lead to goal and dream realization (Isaksen et al., 2011). The creative problem-solving process is crucial because it focuses on finding solutions and resolving problems as well as improving existing environments and situations through cooperation, creative thinking, and critical thinking. In the process, creative thinking allows learners to create the most diverse ideas without immediate judgment as good or bad answers. Choosing and evaluating the best problem-solving method using critical thinking is the subsequent step.

The current teaching and learning management of Science and Technology subjects for Grade 7 students in secondary schools under the supervision of Surin Secondary Educational Service Area Office does not support students in experimentation, inquiry, evidence exploration, and reasoning-based conclusions, which is important for solving problems by using data researching, critical thinking, planning, collaboration, and resolving problems through practice in response to creative, challenging, and novel problems. These activities encourage learners' analytical and synthetic thinking skills, as well as skills in evaluation and producing creative and innovative work. By observing students' learning behaviors, their responses to questions, project completion, explanations, problem-solving strategies from assigned situations, or their performance on written exams, it is revealed that the factor most affecting students' learning is their inability to apply prior knowledge to construct diverse and systemetic problem-solving approaches or to create innovations. In semester 1 of the 2024 academic year, the students studying Science were found to lack creativity; they always applied their familiar ways to solve problems. What happen with the Thai students align with Gordon (1998, cited in Khammanee, 2016) who describes that individuals usually hold on to the problem-solving methods they are familiar with and that leads to narrow and uncreative thinking. To think differently and creatively, a person must have chances to solve problems using new ways that have never been considered before. What's more, having people from different backgrounds and experiences working cooperatively can yield wider and more effective methods to solve problems.

According to the aforementioned problems, the researcher studied innovations aimed at improving students' creative problem-solving abilities, giving students opportunities that lead to new discoveries, rapid problem-solving, and outstanding innovative productions. With such abilities, students gain higher academic achievement. More importantly, in today's highly competitive world, continuous development and readiness for progress into the future is essential. Thus, STEM education, an integrated teaching and learning approach, combines four core subjects: Science (S), Technology (T), Engineering (E), and Mathematics (M). Along with STEM concepts, teaching and learning process is managed through activities or projects that integrate knowledge in Science, Mathematics, Technology and Engineering design principles. Students participate in active learning activities to increase their knowledge, understanding, and practice skills in Science, Mathematics, and Technology. Then they apply the learned knowledge and skills to design products or use the methods to respond to their daily life needs or solve their problems. In this process, students seek knowledge and learn interactively with their peers, teachers, and learning environments (Institute for the Promotion of Teaching Science and Technology, 2014).

A growing body of research demonstrates that STEM-based instructional approaches are effective in fostering students' problem-solving abilities. Parno et al. (2019) found that the integration of PBL-STEM significantly enhanced high school students' problem-solving skills in the topic of optical instruments compared with PBL alone or conventional instruction. Similarly, Hebebci and Usta (2022) reported that integrated STEM education positively influenced students' problem-solving skills, scientific creativity, and critical thinking dispositions at the middle school level. Extending this perspective, Zeeshan et al. (2021) argued that STEM learning approaches play a crucial role in preparing learners with problem-solving competencies demanded by Industry 4.0. Research with younger learners has also shown benefits: Yalçın and Erden (2021) demonstrated that STEM activities structured around the design thinking model improved preschool children's creativity and problem-solving skills, while Karamustafaoğlu and Pektaş (2022) highlighted that inquiry-based STEM activities conducted in out-of-school settings significantly promoted secondary students' creative problem-solving and collaboration. Collectively, these studies provide strong evidence that STEM education can effectively cultivate problem-solving competencies across diverse contexts, grade levels, and instructional models. However, few studies have focused on integrating the engineering design process within the STEM framework at the lower secondary level, particularly in the topic of Thermal Energy, which involves abstract concepts that students often find difficult to visualize and apply to real-life situations.

Based on the background and significance of the problems mentioned above, the present study aimed to develop learning activities using the engineering design process within the STEM education framework on the topic of Thermal Energy to enhance Grade 7 students' creative problem-solving abilities. The goals were to help students learn the thinking and design processes in a detailed and sequential manner and connect the components systemically. Through independent research, students were expected to generate creative ideas, design innovations, and apply diverse problem-solving methods to address real-world issues effectively.

Methodology

Participants

The participants consisted of 520 Grade 7 students from 13 classrooms who were enrolled in the second semester of the 2024 academic year at Prasat Witthayakarn School in the Surin Secondary Educational Service Area Office. The sample comprised 39 students from Class 7/12, selected through cluster random sampling using the classroom as the sampling unit. This approach was chosen because classroom-level sampling minimizes disruption to the school's instructional schedule and ensures a naturally occurring learning environment. Although the sample size was relatively small, it was adequate for an experimental design and provided a representative group that included students with high, moderate, and low academic performance. This composition allowed for meaningful analysis of the effectiveness of the intervention across a range of learner abilities.

Research Instruments

Experimental Instrument

The instrument comprised 8 lesson plans totaling 12 teaching hours on the topic of Thermal Energy using the engineering design process within STEM education framework. The lesson plans were reviewed and evaluated by 3 experts using a 5-point Likert scale assessment.

The suitability of the designed lesson plans was analyzed through a tryout which was conducted with 40 Grade 7 students who were not the sample of the study. The result showed that the average suitability score for each lesson plan ranged from 4.33 to 5.00, which met the standard criteria. Therefore, the lesson plans were considered suitable for the study.

Data Collection Instruments

Creative Problem-solving Ability Test

It was a situational-based subjective test designed to assess Grade 7 students' creative problem-solving abilities within the learning context of Thermal Energy through the engineering design process with STEM education framework. The test consisted of 10 problem-solving scenarios. There were only 3 scenarios selected for evaluation. The selected scenarios were designed to assess 4 core components of creative problem-solving:

- Component 1: Understanding the challenges
- Component 2: Generating ideas
- Component 3: Preparing for actions
- Component 4: Planning the approach

Appraising Tasks

Designing the Process

A rubric score method with 1-3 evaluation scale based on the creative problem-solving model by Isaksen et al. (2011) was utilized. The test items with Item Objective Congruence (IOC) assessment of 0.50 to 1.00 were validated and a tryout was conducted with 40 Grade 7 students who were not the selected sample. The item discrimination values (D), based on D.R. Whitney and D.L. Sabers, ranged from 0.28 to 0.80, were selected. The overall reliability of the test using Cronbach's alpha coefficient to calculate was 0.82.

Learning Achievement Test

It was a multiple-choice test with 4 answer choices consisting of 20 items altogether. The test covered the content on Thermal Energy. 3 experts reviewed the test to assess congruence between the questions and the learning objectives for the IOC values. 40 items were initially created and met the IOC criteria. A tryout was carried out with 40 Grade 7 students who were not the selected sample. Based on the difficulty index (p) ranging from 0.28 to o.89, and the discrimination index (B) ranging from 0.24 to 0.90, 30 items were selected. The selected questions were then analyzed for their reliability using Lovett method (Srisa-ard, 2017), which stated the accepted reliability threshold at 0.80 or above. Evidently, the overall reliability of the test was 0.85.

Procedural Setting

A formal letter from Mahasarakham University requesting permission to collect data at Prasat Witthayakarn School was issued. This included asking for administering the Creative Problem-solving Ability Test and the Learning Achievement Test for Grade 7/12 students. It also involves coordinating the dates and times for experiments.

Teacher explained the course description, learning outcomes, and the instructional method through the engineering design process based on STEM education framework on the topic of Thermal Energy to the students.

The sample group was given both pre-tests – the Creative Problem-solving Ability Test and the Learning Achievement Test. The scores were recorded as pre-test scores and the students were given 2 hours to complete the tests.

The experiment was conducted with the sample group using the 8 designed lesson plans. The researcher carried out the experiment, and it lasted 12 hours.

Upon the completion of the designed learning activities, the students were given the post-tests, which were the same as the pre-tests. The students had 2 hours to finish the tests, and their scores were recorded as post-test scores.

The researcher then analyzed the collected data using statistics, summarized, and discussed the results.

Data Collection and Analysis

The efficiency of the learning activities was evaluated using the E1/E2 efficiency formula based on the target criterion of 75/75. The process efficiency (E1) value was calculated from the scores of the knowledge worksheets (K) and creative problem-solving worksheets (P) and students' work. The proportion of scoring was 30-40-30, respectively. The details of scoring are as follows:

The scores of knowledge worksheets (K) and creative problem-solving worksheets (P) were collected from 4 lesson plans consisting of Lesson Plans 1, 3, 5, and 7.

The scores of knowledge worksheets (K), creative problem-solving worksheets (P) and students' work were collected from 4 lesson plans consisting of lesson plans 2, 4, 6, and 8.

The achievement efficiency (E2) value was calculated from the scores of the creative problem-solving ability test and the learning achievement test after all lesson plans were completed. The scoring proportion was 50%from the creative problem-solving ability test and 50% from the learning achievement test.

The creative problem-solving abilities of the students learning through the engineering design process and STEM education framework were compared between the pre-test and post-test scores.

A comparison of the pre-test and post-test scores was conducted to evaluate the students' learning outcomes after learning through activities using STEM-based education and the engineering design process.

Result and Discussion

Part 1: Results of the efficiency analysis of learning activities using the engineering design process within STEM education framework on the topic of thermal energy for grade 7 students

The E1 value was calculated from the scores of the knowledge worksheets (K) and creative problem-solving worksheets (P) and students' work. The proportion of scoring was 30-40-30, respectively. The E2 value was calculated from the scores of the creative problem-solving ability test and the learning achievement test with the proportion of 50-50, respectively. The results are shown in Table 1.

Table 1 Efficiency analysis of the process (E1) and the achievement (E2) of learning activities using the engineering design process within STEM education framework on the topic of thermal energy for grade 7 students

Efficiency of Lesson Plans	Full Score	Total Score	$\bar{x}$	S.D.	Percentage
Efficiency of the Process (E1)	100	3218.95	82.53	2.02	82.53
Efficiency of the Achievement (E2)	100	3122.77	80.07	3.20	80.07

The efficiency of the process is 82.53/80.07

From Table 1, the efficiency analysis of the lesson plans developed using the engineering design process within STEM education framework illustrates that the efficiency of the process (E1) had a mean score of 82.53, 82.53%, and 2.02 standard deviation. The achievement efficiency had a mean score of 80.07, which is equivalent to 80.07% and standard deviation of 3.20. Thus, the lesson plans employing the engineering design process within STEM education framework to enhance creative problem-solving ability on the topic of Thermal Energy for Grade 7 students obtained an overall efficiency of 82.53/80.07.

Part 2: Results of the Analysis of Creative Problem-solving Ability through Learning Activities Using the engineering design process within STEM education framework

Table 2 Results of the Analysis of Creative Problem-solving Ability Scores after Learning through the Activities Using the Engineering Design Process within STEM Education Framework, Compared each Component against the 75% Criterion Using a One-Sample t-test

Evaluation Item	Full Score	$\bar{x}$	S.D.	μ 75%	t	df	P-value
Component 1: Understanding the Challenges	9	7.11	0.63	6.75	3.60	38	0.00*
Component 2: Generating Ideas	9	7.02	0.74	6.75	2.31	38	0.02*
Component 3: Preparing for Actions	9	7.24	0.57	6.75	5.38	38	0.00*
Component 4: Planning the Approach	9	7.04	0.59	6.75	3.05	38	0.00*
	36	28.41	4.17	27	3.58	38	0.00*

*At the .05 level of statistical significance

Based on Table 2, the mean score of the students' ability in creative problem-solving in 4 components was 28.4. The P-value was shown to be less than 0.05 which demonstrated that the students' creative problem-solving abilities were higher than the 75% criterion with the statistical significance at the .05 level.

Table 3 Results of the Comparative Analysis of Creative Problem-solving Ability Scores Before and After Learning through the Designed Activities Using Dependent Samples t-test

Testing	Full Score	$\bar{x}$	S.D.	t	df	P-value
Before Learning	72	38.97	4.34	31.07	38	0.00*
After Learning	72	56.87	2.21			

*At the .05 level of statistical significance

According to Table 3, it shows that all 39 Grade 7 students studying in the classroom that utilized the learning activities applying the engineering design process within STEM education framework on the topic of Thermal Energy had a significant improvement in their creative problem-solving abilities. Before learning, the students' mean score was 38.97 with a standard deviation of 4.34. After learning, the mean score increased to 56.87 with a standard deviation of 2.21. The comparison of the pre-test and post-test scores indicated that students' post-test scores were higher than the pre-test scores at the .05 level of statistical significance.

Part 3: Results of the Analysis of Learning Achievement through the Designed Learning Activities

Table 4 Results of the Analysis of Post-Learning Achievement Scores through Learning Activities Applying the Engineering Design Process within STEM Education Framework on the Topic of Thermal Energy Compared against the 75% Criterion Using a One-Sample t-test

Testing	Full Score	$\bar{x}$	S.D.	t	df	P-value
After Learning	20	16.23	1.01	7.59	38	0.00*

*At the .05 level of statistical significance

Table 4 displays the students' learning achievement when compared against the 75% criterion of the full score. The mean score was 26.23. The P-value of less than 0.05 indicated that the learning achievement scores were higher than the 75% criterion at the .05 level of statistical significance.

Table 5 Results of the Comparative Analysis of Learning Achievement Scores Before and After Learning through the Designed Activities Using Dependent Samples t-test

Testing	Full Score	$\bar{x}$	S.D.	t	df	P-value
Before Learning	20	7.92	2.01	26.62	38	0.00*
After Learning	20	16.23	1.01			

*At the .05 level of statistical significance

Based on the information in Table 5, it shows that the 39 Grade 7 students studying in the class that employed the learning activities using the engineering design process within STEM education framework on the topic of Thermal Energy had a significant improvement in their learning achievement. Before learning, the students' mean score was 7.92 with a standard deviation of 2.01. After learning, the mean score increased to 16.23 with a standard deviation of 1.01. The comparison of the pre-test and post-test scores revealed that students' post-test scores were higher than the pre-test scores at the .05 level of statistical significance.

Conclusion

The developed learning activities using the engineering design process within STEM education framework on the topic of Thermal Energy for Grade 7 students gained an efficiency value of 82.53/80.07. The number of 82.53% was from the mean score of students' Knowledge Sheets, Creative Problem-solving Sheets, and the pieces of their work. And 80.07% was the mean score from the Creative Problem-solving Ability Test and Learning Achievement Test which the students did after all the 8 lesson plans were completed. It is clearly shown that the designed learning plans on Thermal Energy had higher efficiency than the 75/75 criterion set. It is so because the learning plans were developed based on the Core Curriculum for Basic Education B.E. 2551 (A.D. 2008, Revised A.D. 2017) and the school's curriculum. They were also reviewed for accuracy and suitability by the advisors and experts. The framework of STEM education integrating the 4 core subjects encouraged students to apply knowledge from various fields to solve problems, do research, and create innovations relevant to current global situations (Institute for the Promotion of Teaching Science and Technology, 2014). In addition, STEM education enabled students to apply prior knowledge in drafting and designing innovations for solving problems through practices. It also supported students in learning and creating their own experiences encouraging students to apply their knowledge to design and solve creative problems. Teachers presented situations and problems to stimulate students' interests and to make them connect their existing knowledge with the lessons they had learned previously. They worked in group to discuss collaboratively for them to choose the best and most appropriate solution. They designed their own problem-solving processes and used technology for searching additional information as this is how students should learn in the digital era (Ministry of Education, 2008). When the students had sufficient practice, they were able to apply problem-solving skills in their daily lives. They became more proficient and once they could think outside the box, they made faster decisions when facing complex situations. The present study also aligned with the study of Yokasing which studied the development of learning achievement and scientific creativity using STEM-based education on the topic of Work and Energy with Grade 10 students. The study reported the efficiency of 79.32/77.39 and that met the specified criteria.

After the Grade 7 students participated in the designed learning activities, they had higher ability in creative problem-solving than before learning. Their scores were higher than the 75% criterion with statistical significance at the .05 level. The result corresponded to the research hypothesis. It can be explained that the designed learning activities were appropriate for students at this age. Learning involves integration of knowledge in Science, Mathematics, and Technology together with the engineer design process. From using this integrated knowledge, creative problem-solving skills were promoted as students sought new and diverse approaches. Then they took the best one to solve the problems and reached the goal more easily (Isaken et al., 2011). In learning Science, students performed the tasks using scientific methods to discover answers or to build knowledge. They had to understand the problems assigned by the teacher. Students in each group gathered the approaches to solve problems from learning material. They then selected the most appropriate and feasible approach for the given situation by applying the principles of Science, Mathematics, Engineering, and Technology to help solve the complicated problems. Students could explain the methods of problem-solving correctly and clearly in a correct order. The finding of the present study agreed with the study of Matkamjorn, which investigated Grade 8 students' creative problem-solving ability and their academic achievement on the topic of Food and Living using STEM education concepts. The result showed that the students' creative problem-solving ability met the criterion of 70% of the total score. It can be confirmed that STEM education approach promoted creative problem-solving ability in students.

After the Grade 7 students participated in the designed learning activities, they had higher learning achievement than before learning. Their post-test scores met the 75% criterion with statistical significance at the .05 level. This finding conformed to the research hypothesis. It can be stated that the designed learning activities were suitable for the students' age, the data collection instruments were systematically developed by taking the Core Curriculum for Basic Education B.E. 2551 (A.D. 2008, Revised A.D. 2017) and the school's curriculum into account. The teaching and learning process also supported students to construct knowledge by exploring and researching information that they were interested in. The teacher made sure that STEM education framework was integrated in the learning activities (Institute for the Promotion of Teaching Science and Technology, 2014). The employment of engineering design process within STEM education framework into learning activities allowed students to participate in activity-based learning with integration of Science, Mathematics, Technology, and Engineering principles. What also promoted learning was the activity that focused on solving real-world problems because students gained experience and life skills that could lead them to create innovations. Additionally, the designed activities supported members in the group to help each other search for approaches to solve the assigned problem. They also analyzed the problem together and eventually had a clear problem-solving process. The designed learning activities aimed at getting students to learn autonomously through doing worksheets, exchanging ideas with peers and teachers, seeking information from media, and practicing discovering answers creatively. Consequently, students gained creative problem-solving ability and that increased their learning achievement as well. Khotboot (2017) studied the integration of STEM education to enhance learning achievement and attitudes toward Science of Grade 7 students in 2017. It was found that the students' post-test scores exceeded the 80% criterion at the .01 level of statistical significance. Correspondingly, Jamnongtam (2017) developed a science unit on Biomolecules using STEM-based education for Grade 10 students in Bangkok. After learning, the students' post-test scores were higher than pre-test scores and the set criterion at the .01 level of statistical significance.

Based on the findings, teachers are encouraged to incorporate the engineering design process within STEM-based activities as part of their regular science instruction. In practice, this means presenting real-world problems that are relevant to students' lives, guiding them to integrate knowledge from science, mathematics, engineering, and technology, and allowing sufficient time for group discussion, hands-on experimentation, and iterative redesign. Teachers should also act as facilitators by providing scaffolding questions, feedback, and resources while encouraging students to take ownership of their learning. Importantly, lesson plans should align with the national curriculum and be adapted to students' varying ability levels to ensure inclusivity. By following these strategies, teachers can create an engaging learning environment that not only improves problem-solving and academic achievement but also cultivates 21st-century skills such as collaboration, creativity, and independent inquiry.

The findings of this study contribute to the growing body of research confirming the effectiveness of STEM education in developing students' higher order thinking skills. Unlike many previous studies that focused on high school contexts (e.g., Jamnongtam, 2017), this research demonstrates that integrating the engineering design process within the STEM framework can successfully be applied with Grade 7 students in the topic of Thermal Energy. The study not only validated the efficiency of the designed activities against the 75/75 criterion but also highlighted their potential to enhance both creative problem-solving ability and learning achievement in younger learners. This contribution is significant because it provides evidence-based guidelines for designing STEM activities that are developmentally appropriate, curriculum-aligned, and capable of preparing secondary students with the skills required in the 21st century.

One limitation of this study is the relatively small sample size of 39 students drawn from a single Grade 7 classroom. Although the sample was selected through cluster random sampling and represented a mix of high, moderate, and low achievers, it may not fully capture the diversity of learning characteristics found in larger student populations. Therefore, the findings should be interpreted with caution, and generalization to other contexts or schools should be made carefully. Future research should include larger and more diverse samples across multiple schools or regions to strengthen the external validity of the results.

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