Journal of Education, Prince of Songkla University, Pattani Campus
Vol.34 No.3 : September - December 2023, pp. 165-181

Research Article

The Effect of Integration STEM Education with Project-Based Learning on Creative and Critical Thinking Skills Development of Pre-service Chemistry Teachers

Tanchanok Poonsin
Ph.D. (Biotechnology), Lecturer
Department of Science and Mathematics Teaching,
Faculty of Education, Thaksin University
Ninna Jansoon*
Ph.D. (Science and Technology Education), Assistance Professor
Department of Basic Science and Mathematics, Faculty of Science, Thaksin University
*Corresponding author: ninna@tsu.ac.th

Received: December 23, 2022/ **Revised:** June 7, 2023/ **Accepted:** June 14, 2023

Abstract

This research aimed to investigate the impact of project-based learning that integrates with STEM on pre-service teachers' creative and critical thinking skills in the topic of "Garbage Designer: Who Uses Waste as Inspiration for New Products", that pre-service teacher chemistry teacher found and would like to solve waste materials problem in Songkhla old town community. The sample group for this research was 34 pre-service chemistry teachers, Faculty of Education at Thaksin University, Songkhla campus that chosen based on the purposive sampling technique. Qualitative research method was employed in this research. The research tools consisted of 1) Creativity Product Analysis Matrix (CPAM) 2) Paul-Elder Critical Thinking Framework and 3) classroom observation form.

The results of this research showed that STEM Education with project-based learning was able to enhance the average creative and critical thinking skills of pre-service chemistry teachers in all indicators. The enhancement of pre-service chemistry teachers' creative thinking skills was observed by the average scores of pre-service chemistry teachers' creative dimension equal to 72%, and pre-service chemistry teachers' creativity was categorized as good. Moreover, critical thinking skill was also observed, indicated by the mean score of the pre-service chemistry teacher was 3.3 out of 4.0 which was categorized as advanced thinker. Based on the result, STEM Education with project-based learning had a good impact on the improvement of pre-service chemistry teachers' creative and critical thinking. This finding was expected to help the teachers rethink how the pre-service teacher benefit from their involvement in the integrated STEM with project-based learning activities and restructure their teaching strategies to achieve student-centered learning.

Keywords: STEM Education with Project-Based Learning, Critical Thinking, Creative Thinking

บทความวิจัย

ผลของการบูรณาการจัดการเรียนรู้สะเต็มศึกษาร่วมกับโครงงานเป็นฐานต่อการพัฒนาความคิดสร้างสรรค์และการคิดอย่างมีวิจารณญาณของนิสิตครู สาขาเคมี

ธัญชนก พูนศิลป์
ปร.ด. (เทคโนโลยีชีวภาพ), อาจารย์
สาขาการสอนวิทยาศาสตร์และคณิตศาสตร์ คณะศึกษาศาสตร์ มหาวิทยาลัยทักษิณ
นินนาท์ จันทร์สูรย์*
ปร.ด. (วิทยาศาสตร์และเทคโนโลยีศึกษา), ผู้ช่วยศาสตราจารย์
สาขาวิทยาศาสตร์และคณิตศาสตร์พื้นฐาน คณะวิทยาศาสตร์ มหาวิทยาลัยทักษิณ
*ผู้ประสานงาน: ninna@tsu.ac.th

วันรับบทความ: 23 ธันวาคม 2565/ **วันแก้ไขบทความ:** 7 มิถุนายน 2566/ **วันตอบรับบทความ:** 14 มิถุนายน 2566

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของการบูรณาการสะเต็มศึกษาร่วมกับการเรียนรู้โดยใช้โครงงานเป็นฐานเพื่อพัฒนาความคิดสร้างสรรค์และการคิดอย่างมีวิจารณญาณของนิสิตครูภายใต้หัวข้อ *“นักออกแบบขยะผู้ใช้ขยะเป็นแรงบันดาลใจเพื่อการสร้างสรรค์ผลิตภัณฑ์ใหม่”* ซึ่งเป็นหัวข้อที่นิสิตค้นพบและต้องการแก้ไขปัญหาขยะจากชุมชนย่านเมืองเก่าสงขลา กลุ่มตัวอย่างได้แก่ นิสิตครูเคมี คณะศึกษาศาสตร์ มหาวิทยาลัยทักษิณ วิทยาเขตสงขลา จำนวน 34 คน โดยวิธีการเลือกแบบเจาะจง งานวิจัยนี้เป็นงานวิจัยเชิงคุณภาพโดยมีเครื่องมือที่ใช้ในการวิจัยคือ 1) Creativity Product Analysis Matrix (CPAM) 2) Paul-Elder Critical Thinking Framework และ 3) แบบสังเกตชั้นเรียน

ผลการวิจัยพบว่า การจัดการเรียนรู้ตามแนวทางสะเต็มศึกษาร่วมกับการเรียนรู้โดยใช้โครงงานเป็นฐานสามารถส่งเสริมให้นิสิตครูเคมีมีความคิดสร้างสรรค์และการคิดอย่างมีวิจารณญาณในทุก ๆ มิติ โดยนิสิตครูเคมีมีคะแนนเฉลี่ยในมิติของความคิดสร้างสรรค์คิดเป็นร้อยละ 72 ซึ่งอยู่ในเกณฑ์ระดับดี นอกจากนี้นิสิตครูเคมีมีคะแนนเฉลี่ยในมิติของการคิดอย่างมีวิจารณญาณเท่ากับ 3.3 ของคะแนนเต็ม 4.0 ซึ่งอยู่ในเกณฑ์ระดับนักคิดขั้นสูง ผลจากการวิจัยบ่งชี้ว่าการจัดการเรียนรู้ตามแนวทางสะเต็มศึกษาร่วมกับการเรียนรู้โดยใช้โครงงานเป็นฐานส่งผลดีต่อการพัฒนาความคิดสร้างสรรค์และการคิดอย่างวิจารณญาณของนิสิตครู ซึ่งการค้นพบนี้คาดว่าจะช่วยให้ผู้สอนกลับมาทบทวนใหม่ว่านิสิตครูจะได้รับประโยชน์อย่างไรจากการจัดการเรียนรู้ด้วยสะเต็มศึกษาร่วมกับการเรียนรู้โดยใช้โครงงานเป็นฐานและปรับโครงสร้างกลยุทธ์การสอนเพื่อให้บรรลุการเรียนรู้ที่เน้นผู้เรียนเป็นสำคัญ

คำสำคัญ: สะเต็มศึกษาร่วมกับการเรียนรู้โดยใช้โครงงานเป็นฐาน การคิดอย่างมีวิจารณญาณ ความคิดสร้างสรรค์

Introduction

With the advancement in technology, the career path is also changed which hard to imagine the career for future. For this reason, the cognizant center for the future of work has studied and reported the jobs of the future 2030. Garbage designer is one of the important future careers due to a new form of garbage recycling called "upcycling" expected popular work in the future (Wattanakit & Khwunsuwan, 2021). Upcycling is the practice of turning waste into better quality products; for example, toothbrushes waste into bracelets, or used magazines paper into woven mats or plant pots. Garbage designers are an important role to ensure the success of upcycling. There are expected that garbage designers can create ways to turn the by-products of the manufacturing process into new material for making high-value product (Wattanakit & Khwunsuwan, 2021).

The topic mentioned above demonstrates that market demands in the 21st century require employees to have capabilities in critically overcoming problems and producing creative solutions (Nakano & Wechsler, 2018). Moreover, progress in science and technology, human brain research and necessary skills for people in the 21st century have caused many changes in education strategies for all grade levels. Educators say that education in the 21st century should teach learners to master higher-order thinking skills (Chonkaew et al., 2016).

Higher-order thinking skills, especially critical and creative thinking skills, are one of the important skills that are required as a powerful tool in the 21st century when changes and developments in the field of education are very fast. It is crucial to prepare students to be able to think critically and creatively. Critical thinking involves analysis and evaluation rather than only accepting ideas or information. Advanced critical thinking skill involves six basic cognitive aspects, i.e. interpretation, analysis, evaluation, conclusions, explanations and self-regulation. The ability to think critically would allow the students to think rationally in overcoming problems. It also helps students to create and develop alternative solutions to the problems (Retnaningsih et al., 2020).

Similarly critical thinking skill, creative thinking skill is important cognitive aspects required for meaningful learning in all disciplines. Creative thinking skill aims to synthesize ideas, generate new ideas, and determine the effectiveness of the existing ideas. Creative thinking skill could train students to develop many ideas and arguments, ask questions, acknowledge the truth of an argument, and even enable students to be open and responsive to different perspectives. Creative thinking skill in science learning could open new perspectives for students to provide answers to science problems (Sumarni & Kadarwati, 2020)

In Thai education, the findings of science educators and scholastic documents show that there have been numerous problems that impede the success of higher-order thinking skills development for Thai students (Chonkaew et al., 2016). The recent evidence that reflected the recession of Thai education system was the result of the Programme for International Student Assessment (PISA). The assessment focused on how learners applied their knowledge to solve problems in their real lives rather than in their school curriculums. The results of the latest year (2018) revealed that Thai students' scores were still lower than the mean scores of the most participating countries-Thailand was ranked 55th among the 79 participating countries (OECD, 2018). The main cause of low scores was that Thai students were weak in higher-order thinking skills. Chonkaew et al. (2016) revealed that traditional teaching method is commonly used in Science. Moreover, science teaching and learning promoted the ways or techniques on how to understand the concepts, principles, and theories (Darling-Hammond et al., 2019). This indicated that the concern of the learning process has not fully covered the critical, evaluative and creative thinking skills. Perhaps one method of developing critical and creative thinking skills is through improving students' understanding of Science, Technology, Engineering and Mathematics (Fan & Yu, 2017). STEM Education is an approach that integrates science (S), technology (T), engineering (E), mathematics (M) and has especially brought innovation to science education. STEM education is relevant because in the nature of the world, each discipline (S-T-E-M) does not exist alone and complex and multidimensional problems are encountered by all (Hafni et al., 2020).

Utami et al. (2020) divides thinking styles into five categories, namely superior creative thinking styles, creative thinking styles, balanced thinking styles, critical thinking styles, superior critical thinking styles. These thinking styles have advantages and disadvantages to each, especially in terms of solving problems. Creative thinking styles need to improve their critical thinking skills to overcome problems. In contrast, someone who has a critical thinking style needs to sharpen their creative thinking abilities to produce unique ideas in problem-solving situations (Wechsler et al. 2018).

Creative and critical thinking styles can be integrated with the STEM approach (Altan and Tan, (2021), Reynders (2020) and improved in different ways (Saien et al., 2019). Improving creative thinking styles is to present a learning process that requires students to have an open mind (Wechsler et al. 2018). An example is learning that uses discussion methods that can encourage students to have an open mind in developing their ideas (Wechsler et al. 2018). At the same time, a critical thinking style requires a learning environment that provides a problem and demands the best solution by testing it on a brief evaluative exercise (Wechsler et al. 2018). STEM learning can facilitate both because this learning is presented with concrete problems that students must solve with an open mind to determine the best solution. Because STEM learning is not only learning concepts but more on how to use these scientific concepts in relation to daily life. This is where the ability to think creatively or critically is used. Integration between science, technology, engineering, and math is a unity that cannot be separated from STEM Education.

Based on the preliminary study of pre-service physics teachers found that 32% of students have a balanced thinking pattern, 57% critical thinking, 9% creative thinking, and 2% superior critical thinking. There are no students who have superior creative thinking patterns, and only one person who has superior critical thinking patterns. On the other hand, STEM Education with project-based learning might provide a good teaching practice to improve the pre-service teachers' creative and critical thinking skills. Due to the great importance of those two skills for pre-service teachers, the effect of the implementation of STEM Education with project-based learning on pre-service teachers'critical and creative thinking skills will be clearly explained in the paper.

Purpose of the Study

To investigate the effect of integrated STEM with project-based learning implementation on creative and critical thinking skills of pre-service chemistry teachers in the concept of *“Garbage Designer: Who Uses Waste as Inspiration for New Products”.*

Methodology

1. Research Method

The study used qualitative research. The qualitative data included classroom observations and pre-service teachers’ products. In collecting data, the researcher has a role as non-participant in the study. In non-participant observation study, the researcher only observes the activities in the class and not directly involves in the observed situation (Hanif et al., 2019).

2. Research participant

This study is conducted in a university that is located in Songkhla, Thailand. The research university is a government university. The research participants included 34 pre-service teachers (8 males and 26 females), studying in the third year in Bachelor of Education (Chemistry) at Faculty of Education chosen with purposive sampling technique.

3. Data collection and analysis

This study utilized qualitative method in the collection and analysis of data. The qualitative research tools consisted of Creativity Product Analysis matrix (CPAM) developed by Besemer (1998). The Creative Product Analysis Matrix (CPAM) may be used as a framework for thinking about the creativity manifested in many different kinds of products. For example, the model can be used in respect to works of art, new product ideas in manufacturing, or when considering other types of artifacts of the creative process. The model posits three related factors: Novelty, Resolution, and Elaboration. Within the three factors or dimensions, nine component facets are hypothesized. Falling under the rubric of Novelty are the facets for original and surprise. In the category of Resolution, the facets are valuable, logical, useful, and understandable. The third dimension of the model, Elaboration includes the following facets: organic, elegant, and well crafted. The pre-service chemistry teachers’ creativity is scored by 1 to 3 scale for each criterion of creativity.

For pre-service chemistry teachers’ critical thinking, the data were analyzed based on the Paul-Elder critical thinking framework. Paul and Elder critical thinking framework was one of the frameworks used by some researchers to analyze critical thinking because this framework was general in engineering, natural science, social science, and linguistics. In critical thinking, there are six stages consist of 1) unreflective thinker, 2) challenged thinker, 3) beginning thinker, 4) practicing thinker, 5) advanced thinker and 6) master thinker (Paul & Elder, 2009). Scores form critical thinking rubric were compared with criteria of critical thinking development based on stages of critical thinking development (Paul & Elder, 2009). The critical thinking of pre-service chemistry teachers was evaluated with four dimensions of critical thinking comprising of 1) purpose and question (clearly identify the purpose including all complexities of relevant questions), 2) information (accurate complete information that is supported by the relevant evidance), 3) assumption and point of view (complete, fair presentation of all relevant assumptions and point of view), and 4) implications and consequences (clearly articulates significant, logical implications and consequences based on relevant evidence). Critical thinking of pre-service chemistry teachers is graded on a 1 to 4 scale for each dimensions of critical thinking.

4. Research Procedure

This study was used the topic of "Garbage Designer: Who Uses Waste as Inspiration for New Products" as the theme of creative design, and designed and planed learning activities. The activities were carried out in accordance with the four stages of STEM with project-based learning as already mentioned in research works (Lou et al., 2017). The stages were used in this study consisting of preparation, implementation, presentation and evaluation, and correction which were the flow for pre-service chemistry teachers. This study needs fourth meeting to finish all stages of STEM with project-based learning, i.e. (1) First meeting, researcher conducted preparation stage which leads pre-service teachers to understand the theme and scope, (2) Second meeting, researcher conducted implementation stage which let pre-service teacher to create the product based on their design drawing, (3) Third meeting, researcher conducted presentation and evaluation stage that give opportunities for others to give suggestion regarding the project that are presented, and (4) Fourth meeting, researcher conducted correction stage which give pre-service teachers opportunity to improve their products. Table 1 represents activities of each stage in the integrated STEM with project-based learning implementation.

Table 1

The integrated STEM with project-based learning activities of each stage

Stage	Periods	Activity
1. Preparation	4 week	1. Pre-service chemistry teachers surveyed the problem in Songkhla old town communication. 2. Teacher conducted preparation stage for pre-service chemistry teachers to understand the theme and scope in the topic of "Garbage Designer: Who Uses Waste As Inspiration For New Products" 3. Pre-service chemistry teachers found the information regarding the basic concept in making project. 4. Pre-service chemistry teachers discussed on tools and materials used and produced design drawing.
2. Implementation	2 week	1. Teacher conducted implementation stage which let pre-service chemistry teachers create the product based on their design drawing.
3. Presentation and evaluation	2 week	1. Pre-service chemistry teachers presented their product and basic concept of the product. 2. Three science educators evaluated pre-service chemistry teachers' product.

Table 1

Stage	Periods	Activity
		3. Teacher gave opportunities for others to provide suggestion regarding the project presented.
4. Correction	2 week	1. Teacher gave pre-service chemistry teachers opportunity to improve their product. 2. Pre-service chemistry teachers made self-correction about the product according to suggestion and feedback.

Research Findings

The research findings of this study are presented in the following sections.

1. Characteristic of STEM with project-based learning

STEM teaching and learning is a quite new pedagogical strategy in Thailand. It is a student-centred approach in order to achieve engagement with multi-disciplines. Encouraging more students to participate in the enabling sciences and technology requires teachers or facilitators who have a good understanding of integrated STEM instructional strategies, engineering practices, and its applications. In this study, pre-service chemistry teachers made the new product from plastic waste by upcycling based on the STEM field. The integration of STEM in making the new product from plastic waste activities can be shown in Table 2.

Table 2

The integration of STEM in making the new product from plastic waste

Science (S)	Technology (T)	Engineering (E)	Mathematics (M)
The physical and chemistry characteristics of plastic waste upcycling process	Find information from the internet/ textbook. Decide the tool and materials. Selecting the plastic waste to make a product	Designing its drawing the product (prototype)	Statistic, pattern, correlation and shape that was calculated to produce the product

Science (S) field in this study discussed the concept of upcycling from plastic waste. Before making the new product from plastic waste, pre-service chemistry teachers should recognize how is the turning plastic waste into better quality products. If pre-service chemistry teachers already understand about the properties of the plastic waste, they are able to design the new product from plastic waste. In this concept, pre-service chemistry teachers were expected to determine the physical and chemistry characteristics of plastic waste and process of upcycling, so the new product was produced from plastic waste by upcycling process. Mathematics (M) in this study referred to statistic, pattern, correlation and shape that was calculated to produce the product.

Technology (T) field in this study can be seen in preparation stage when pre-service chemistry teachers used the internet/textbook to find any information that was needed in making a new product. Moreover, pre-service chemistry teacher should make their decision to select the suitable tools and materials. This situation encouraged pre-service chemistry teachers to design the new products from plastic waste. Engineering (E) in this study can be observed in the preparation stage when chemistry pre-service teachers made their own design drawing. Design drawing that was made by pre-service chemistry teachers should be suitable with the concept of upcycling the plastic waste. In order to make pre-service chemistry teachers easier to construct the new product, pre-service chemistry teachers were expected to put detail information in their design drawing, such as method of upcycling, type, physical and chemistry properties of plastic. The integration of STEM in making the new product from plastic waste in the concept of “Garbage Designer: Who Uses Waste As Inspiration For New Products” is shown in Figure 1. The design drawing of pre-service chemical teachers after implementing STEM with project-based learning is presented in Figure 2.

Figure 1

The examples of the integration of STEM with project-based learning in making the new product from plastic waste.

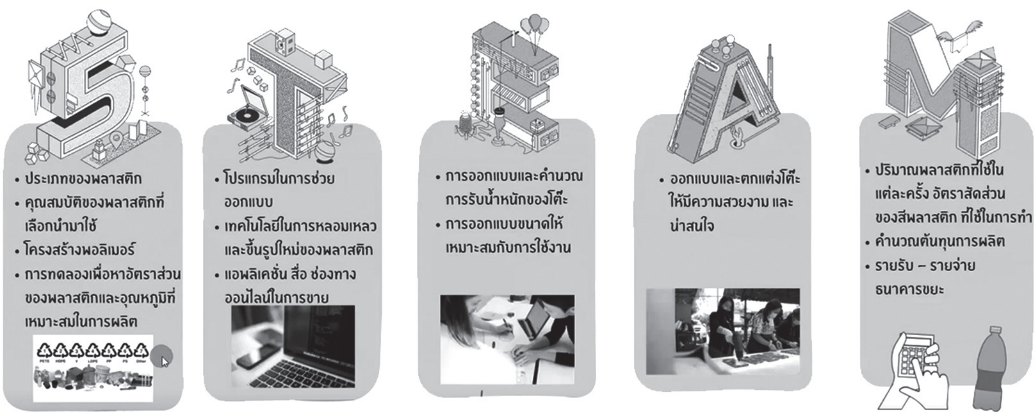
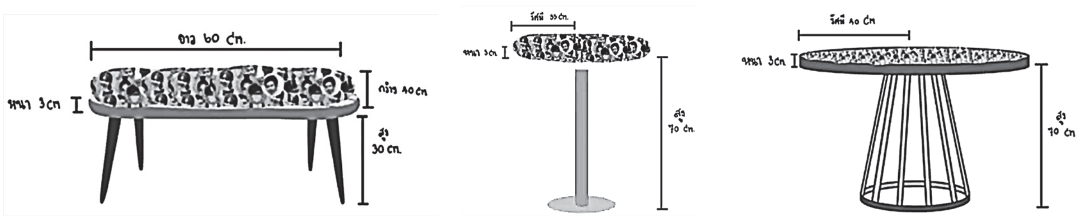


Figure 2

The examples of pre-service chemistry teachers' design drawing (prototype) in the concept of "Garbage Designer: Who Uses Waste As Inspiration For New Products" after implementing STEM with project-based learning.

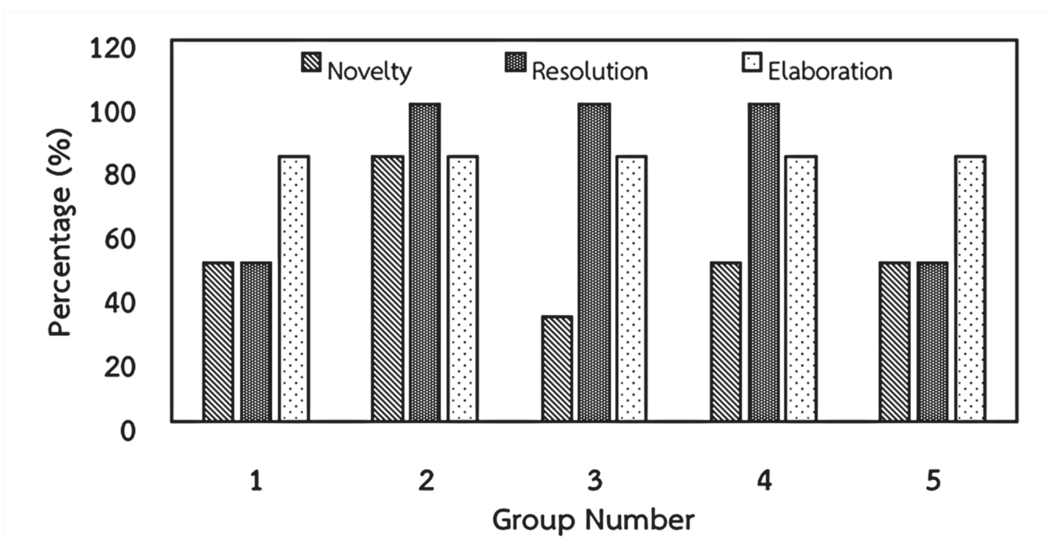


2. Pre-service teachers' creativity

The result shows the qualitative data based on creativity rubric assessment. Pre-service chemistry teachers' creativity was evaluated from their product as resulting from mini-project learning on the topic of "Garbage Designer: Who Uses Waste as Inspiration for New Products" by using the Creative Product Analysis Matrix (CPAM). The obtained data were based on the criteria of each creativity dimension measurement which is scored with a rubric scale from 1 to 3 based on several requirements. The result of creative thinking of each group in pre-service chemistry teacher class is shown in Figure 3.

Figure 3

Pre-service chemistry teachers' creativity dimension for each group



The result as shown in Figure 3, indicated that the pre-service chemistry teachers in Group 2 had the highest percentage of creativity (90%) categorized as very good. Meanwhile, the lowest of creativity percentage was the pre-service chemistry teachers in Group 1 and 5 (61%) who were classified as pass of creativity. This result suggested that each group had different achievements of creativity. The learning process for the development of creative ideas of each group was also different due to the class was divided into groups when making the product. Hence, each group worked and discussed together to develop their idea for creating a product (Hanif et al., 2019). Also, the average creative thinking skill of pre-service chemistry teachers in each dimension was evaluated after implementing STEM with project-based learning (Table 3).

Table 3

Pre-service chemistry teachers' creativity result

Creativity Dimension			Average	Category
Novelty	Resolution	Elaboration		
58%	80%	83%	74%	Good*

*Scoring guide: 80%-100% very good; 70%-79% good; 60%-69% pass; 50%-59% lack

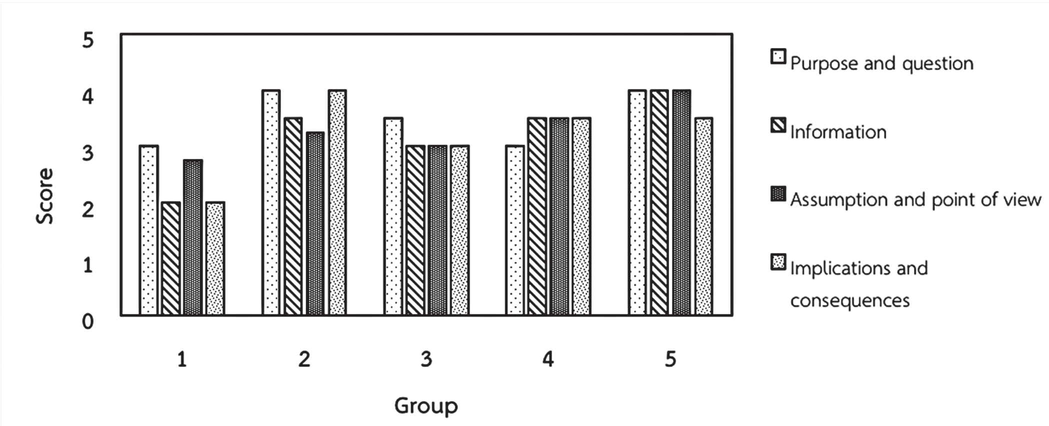
As shown in Table 3, each creativity dimension of pre-service chemistry teachers had different attainments. The dimension of novelty, resolution and elaboration obtained 58%, 80% and 83%, respectively. The average score of each dimension of creativity after the stage of implementation in the integrated STEM with project-based learning was 74% which categorized as good. For novelty dimension, the pre-service chemistry teachers' products were inspiring others to try something new and pre-service chemistry teachers used the previous finding as their idea, but they made a modification of the products. Resolution dimension, pre-service chemistry teachers' products were compatible with the purpose, related to the concept and can be used continuously without any requirement. Elaboration dimension, the products were done well with the good looking design and were presented in a communicative way and understandable manner. From the results, it was suggested that pre-service chemistry teachers who learned through integrated STEM with project-based learning had good creativity. Pre-service chemistry teachers were trained to realize their ideas by designing and constructing the product in integrated STEM with project-based learning. Also, they were given the opportunity to develop their idea by using several tools and materials that can improve the quality of the product. Therefore, it could be inferred that learners who learned science by using integrated STEM with project-based learning had good creativity. From the result, it could be concluded that integrated STEM with project-based learning showed a significant effect on the improvement of pre-service chemistry teachers' creative thinking skills.

3. Pre-service teachers' critical thinking

The pre-service chemistry teachers' products were analyzed using critical thinking rubric. The result of pre-service chemistry teachers' critical thinking of each group in class is depicted in Figure 4.

Figure 4

Score of pre-service chemistry teachers' critical thinking



As shown in Figure 4, there was different achievement of critical thinking for each group. The highest pre-service chemistry teachers' critical thinking score (3.88) was found in Group 5. Group 1, the lowest critical thinking score (2.44) was obtained. The average score of each critical thinking dimension of pre-service chemistry teachers after implementing STEM with project-based learning was obtained 3.3 which categorized as advanced thinker (Table 4).

Table 4

Pre-service chemistry teachers' critical thinking result

Critical thinking Dimension				Average	Category
Purpose and question	Information	Assumption and point of view	Implications and consequences		
3.5	3.2	3.3	3.2	3.3	Advanced thinker*

* Scoring of critical thinking development (Paul & Elder, 2009)

3.51-4.00 Master Thinker; 3.11-3.50 Advanced Thinker; 2.41-3.10 Practicing Thinker; 1.71-2.40 Beginning Thinker; 1.01-1.70 Challenged Thinker; 0.00-1.00 Unreflective Thinker

Advanced thinkers (higher thinker) regularly critiqued their own plan for systematic practices and improve it. Moreover, Advanced thinkers had established good habits of thought which were "paying off". Advanced thinkers tried various methods and combined the method to get best solution. Based on these habits, advanced thinkers not only analyzed their thinking in all the significant domains of their lives but also had significant insights into problems at deeper levels of thought. While advance thinkers were able to think well across the important dimensions of their lives, they are not yet able to think at a consistently high level across all of these dimension. Advance thinker had good general commands over their egocentric nature. They continually strived to be fair-minded and sometimes lapsed into egocentrism and reason in one side way (Paul & Elder, 2009). From the results, it was suggested that behaviors of pre-service chemistry teachers clearly showed an improvement in their critical thinking after participating in STEM with project-based learning. The STEM with project-based learning helped students not only memorize the concepts but also their relationship to technology, engineering, and mathematics. They also related the concepts to the applications in daily life, especially in various elements of the culture that could survive until now (Sumarni & Kadarwati. 2020). The level of achievement of students' critical thinking was also supported by the presence of challenges in solving the problems through project assignments. In project-based learning, the students would collaboratively try to arrange their knowledge in solving the problems and trying various solutions that encourage critical and creative thinking (Darling-Hammond et al., 2019).

The successful implementation of the STEM with project-based learning was inseparable from the learning process. The problems raised in the project-based learning were semi-open problems, which means the answer to the problem was uncertain (Baharin et al., 2018). The STEM with project-based learning allowed the pre-service chemistry teachers to develop possible answers by collecting and analyzing data to solve the problems. The pre-service chemistry teachers were happy to be involved in doing real activities. They were also happy to directly observe traditional processes during the teaching/learning process. As a learning model that challenged the pre-service chemistry teachers to learn and work together with their groups to find solutions to real problems, the project assignments given to the pre-service chemistry teachers have stimulated them to understand the concepts being learned in creating products (Sumarni et al., 2020). This proved that the STEM with project-based learning was an innovative learning approach to improve the pre-service chemistry teachers' problem-solving skills. This approach required collaboration, peer communication, and independent learning.

The effectiveness of the implementation of the STEM with project-based learning in improving the pre-service chemistry teachers' critical and creative thinking was not as expected as previously mentioned. However, this study has provided insight into the implementation of the STEM with project-based learning activities in university as an effort to improve the pre-service teachers' critical and creative thinking skills. This finding was expected to help the teachers to rethink how the students benefit from their involvement in the integrated STEM with project-based learning activities and restructure their teaching strategies to achieve student-centered learning.

Conclusion and Discussion

1. Applying project-based learning strategies to the learning of STEM knowledge assisted pre-service teachers in creative and critical thinkings.

Integrative STEM with project-based learning was used to improve pre-service chemistry teachers' creative and critical thinking skills. The result was in line with the reported earlier (Han et al., 2014). They reported that the average achievement of students' creative thinking skill after the implementation of STEM problem-based learning was significantly different from that before the implementation of the learning model. Sumarni and Kadarwati (2020) suggested that ethano-STEM with project-based learning was an appropriate learning model to help the students to develop flexibility in thinking. This model learning proved that the students' creative thinking activities and abilities would be higher when they carried out the discussions or experiments in groups in comparison with receiving information from the teacher. A similar result was found in the previously reported (Chou et al., 2017). They reported that the STEM with project-based learning gave the positives influence on the effective development of students' creativity. The result of this study was also in line with the results reported earlier (Han et al., 2016). It was reported that the achievement of students' creative and critical thinking skills after the implementation of STEM with project-based learning was significantly higher than before the implementation of the learning model.

Integrative STEM was used to improve pre-service teachers' STEM knowledge and higher-order thinking skills through the use of project-based learning (Haryadi & Pujiastuti, 2022). Real-life based learning activities assisted pre-service chemistry teachers in realizing the importance of theories and fundamental science knowledge. Such activities allowed the pre-service chemistry teachers the opportunity to learn together and to exchange their ideas and experiences, and in turn, created an atmosphere that promoted thinking development among the pre-service chemistry teachers. In addition, in the presentation session, pre-service chemistry teachers' thinking and the creation of tools or useful things resulted in the development of their thinking process as interaction among pre-service chemistry teachers and between pre-service chemistry teachers and in-service teachers.Consequently, this led to an expansion of the pre-service chemistry teachers' scope of thinking to become larger and more complex. Higher-order thinking skills, especiallly, creative and critical thinking skills require a high level of flexibility in understanding how to integrate and apply conceptual knowledge and procedural skills with a complex problem context. The process of thinking before acting is a critical stage for a well-planned design. They could use scientific methods in creating new innovation efficiently, consequently they could practice multiple skills. Moreover, they enjoyed the learning activities and became eager to learn with the result of making high learning achievement that met the prescribed goals (Chonkaew et al., 2016).

2. Characteristics of the STEM integrated with project-based learning activities. The teacher should design opportunities for pre-service chemistry teachers with rigorous learning experiences that require higher-order cognition. Real-world task activities affected pre-service chemistry teachers' skills (Burrows et al., 2014) such as "upcycling" also known as creative reuse. It is the process of transforming by-products,

waste materials, useless, or unwanted products into new materials or products perceived to be of greater quality. The teacher should manage learning with an emphasis on creative and critical thinkings. The learning management should allow the pre-service chemistry teachers to learn how to manage things, to cope with challenging situations, and to apply what they have learned to daily life activities. The teacher should also develop an assessment of STEM learning to evaluate not only what pre-service chemistry teachers know but also how they use their knowledge. Based on the implementation of all four activities in this study, the conclusions are as follows. (1) The stage of preparation: teacher guided pre-service chemistry teachers to understand the theme. (2) The stage of implementation: pre-service chemistry teachers acted as the main actors to strengthen their hands-on ability and problem-solving competence. (3) The stage of presentation and evaluation: pre-service chemistry teachers were trained to foster their capacity to summarize key points ("Garbage Designer: Who Uses Waste as Inspiration for New Products") and express themselves. For evaluation, the diversified evaluation mechanism helped the pre-service chemistry teachers think more meticulously and thoroughly. (4) The stage of correction: pre-service chemistry teachers were encouraged to make corrections according to the feedback and suggestions and improve their own abilities. In summary, after participating in the STEM with project-based learning, most pre-service chemistry teachers agreed that the design of these activities could improve their creativity, critical thinking, and ability in STEM learning and application. Hanif et al. (2019) reported that STEM education showed comprehensive characteristics, i.e. problem solving, critical analysis, and providing students with opportunities to practice their thinking skills. Moreover, these results were consistent with the STEM research results of Mater et al. (2020), who found that the STEM activities help students to work step by step until they reached the final goal of activity, provided students meaningful experiences and boosted students' critical thinking significantly. The result of this study also in the line with the previous finding which stated that STEM approach, especially in hand-on activity through project-based learning, requires students to think critically and creatively (Siew et al., 2015). Therefore, STEM integrated with project-based learning could be used as alternative teaching strategies in university.

Recommendations

Recommendations for practical application

In designing STEM with project-based learning activities, teachers have to effort explaining basic knowledge and skill, allocate a good deal of time, and provide numerous demonstrations for pre-service teachers to practice their creative and critical thinking skills and STEM knowledge. However, an explicit connection presented between the problem or task content and STEM knowledge is crucial component. The tasks chosen should aid pre-service teachers in performing authentic opportunities to observe, acquire, apply, and consolidate ideas. The learning strategy designed by a cooperative group of educators from multi-disciplines would be perfect.

Collaborative group activity learning may encourage pre-service teachers to be more confident in debating and learning in class. They should be provided with opportunities for working in groups to practice sharing their ideas while discussing and listening to the ideas of others. Teachers should set available sessions as many times as possible for giving pre-service teachers opportunities to present their thinking processes. These will reflect their conceptual knowledge, creative and critical thinking skills. In addition, their communication skills will also improve.

Recommendations for future research

1) The development of analytical thinking ability of pre-service teacher through STEM Education should be further investigated.

2) The enhance of higher -order thinking skills and attitudes towards science learning of high school students should be studied.

Acknowledgements

The authors would like to express their appreciation to all the pre-service chemistry teachers who participated in the study. Department of Science and Mathematics Teaching, Thaksin university was also acknowledged.

References

Altan, E. B., & Tan, S. (2021). Concepts of creativity in design based learning in stem education. *International Journal of Technology and Design Education, 31,* 503–529.

Baharin, N., Kamarudin, N., & Manaf, U. K. (2018). integrating stem education approach in enhancing higher order thinking skills. I*nternational Journal of Academic Research in Business and Social Sciences, 87,* 810–822.

Besemer, S. P. (1998). creative product analysis matrix: testing the model structure and a comparison among products -Three novel chairs. *Creativity Research Journal, 11*(4), 333-346.

Burrows, A. C., Breiner, J. M., Keiner, J., & Behm, C. (2014). Biodiesel and integrated stem: vertical alignment of high school biology/biochemistry and chemistry. *Journal of Chemical Education, 91*, 1379–1389.

Besemer, S. P., & Treffinger, D. (1981). Analysis of creative products: Review and synthesis. *The Journal of Creative Behavior, 15*(3), 158–178.

Breiner, J. M., Johnson, C. C., Harkness, S. S., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of stem in education and shelly sheats harkness partnerships. *School Science and Mathematics, 112*(1), 3-11.

Chonkaew, P., Sukhummek, B., & Faikhamta, C. (2016). Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (stem education) in the study of stoichiometry. *Chemistry Education Research and Practice, 17,* 842-861.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2019). Implications for educational practice of the science of learning and development. *Applied Developmental Science,* 1-44.

Fan, S. C., & Yu, K. C. (2017). How an integrative stem curriculum can benefit students in engineering design practices. *International Journal of Technology and Design Education, 27,* 107-129.

Hafni, R. N., Herman, T., Nurlaelah, E., & Mustikasari, L. (2020). The Importance of science, technology, engineering, and mathematics (STEM) education to enhance students' critical thinking skill in facing the industry 4.0. *Journal of Physics: Conference Series, 1521*(4), 042040.

Han, S., Capraro, R., & Capraro, M. M. (2014). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education, 13*(5), 1089–1113.

Han, S., Rosli, R., Capraro, M. M., & Capraro, R. M. (2016). The effect of science, technology, engineering and mathematics (STEM) project-based learning (PBL) on students' achievement in four mathematics topics. *Journal of Turkish Science Education, 13*(special), 3-29.

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhance students' creativity through STEM project-based learning. *Journal of Science Learning, 2*(2), 50-57.

Haryadi, R., & Pujiastuti, H. (2022). enhancing pre-service physics teachers' higher-order thinking skills through STEM-PjBL model. *International Journal of STEM Education for Sustainability, 2*(2), 156-171.

Lou, S. J., Chou, Y. C., Shih, R. C., & Chung, C. C. (2017). A Study of creativity in CaC2 steamship-derived stem project-based learning. *EURASIA Journal of Mathematics Science and Technology Education, 13*(6), 2387–2404.

Mater, N. R., Hussein, M. J. H., Salha, S. H., Draidi, F. R., Shaqour, A. Z., Qatanani, N., & Affouneh, S. (2020). The effect of the integration of STEM on critical thinking and technology acceptance model. Educational Studies, 1-17.

Meikiasari, M., Rahmawati, Y., Delina, M., & Fitriani, E. (Eds.) (2020). The implementation of STEM learning on creative-critical thinking styles (study on pre-service physics teacher). *AIP Conference Proceedings.* AIP publishing. https://doi.org/10.1063/5.0041991

Nakano, T. D. C., & Wechsler, S. M. (2018). Creativity and innovation: Skills for the 21st century. *Estudos de Psicologia (Campinas), 35*(3), 237-246.

OECD. (2018). *Pisa 2018 result combined executive summaries volume I, II & III.* https://www. oecd. org/pisa/Combined_Executive_Summaries_PISA_2018.pdf

Paul, R. W., & Elder, L. (2009). *The miniature guide to critical thinking concepts & tools.* (6th ed.). Rowman & Littlefield Publishers: Washington, DC.

Retnaningsih, R., Kindiasari, A., & Nurdiyanto, H. (2020). Blended learning learning model to improve critıcal thinking skills. *Journal of Critical Reviews, 7*(19), 2289–2292.

Reynders, G., Lantz, J., Ruder, S. M., Stanford, C. L., & Cole, R. S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. *International Journal of STEM Education, 7,* 2-15.

Saien, S., Tee, T. K., Yunos, J. M., & Yee, H. M. (2019). Thinking style pattern among design and technology teachers in Malaysia. *Journal of Technical Education and Training, 11*(3), 43–48.

Siew, N. M., Amir, N., & Chong, C. L. (2015). The perceptions of pre-service and in-service teachers regarding a project-based STEM approach to teaching science. *SpringerPlus, 4*(1), 1-20.

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Journal Pendidikan IPA Indonesia, 9*(1), 11-21.

Wattanakit, S., & Khwunsuwan, W. (2021). Adding value to waste for decoration products: Prototype communities in Khaoroopchang Municipality, Songkhla Province Thailand. *Journal of Architecture, Design and Construction, 3*(2), 13-27.

Wechsler, M. S., Saiz, C., Rivas, S. F., Vendramini, C. M. M., Almeida, L. S., Mundim, M. C., & Franco, A. (2018). Creative and critical thinking: Independent or overlapping components? *Thinking Skills and Creativity, 27,* 114-122.