The Effect of Project Based Learning Model with STEAM Approach Assisted by 4D Frame+BS Media and Learning Motivation to Improve Critical Thinking Skills

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Abstract. This research discusses the effect of STEAM class projects and learning motivation on students' critical thinking skills in the concept of quadratic equations and functions. The study involved two classes as control and experimental classes in a school in Peureulak, where students were assigned to design a bridge structure using 4D Frame+BS media. Students' critical thinking skills and learning motivation were assessed using a descriptive test and a closed-ended questionnaire, then the data were analysed using a two-way ANOVA test. The results showed that the STEAM project, together with increased learning motivation, resulted in improved students' critical thinking skills. This study highlights the potential of project-based learning in STEAM classes to address the gap in learning motivation in this area. However, further research is needed in this area as current research on this topic is limited.

Keywords: Critical, Media, Model, Motivation, Project.

1 Introduction

Critical thinking is a fundamental skill that enables individuals to effectively navigate the complexities of the modern world. It involves the ability to systematically and rationally analyze, evaluate, and reconstruct information, ultimately resulting in more informed and reasonable decisions [5]. The importance of critical thinking skills cannot be overstated, as these skills are essential in both academic and real-world contexts. In an educational setting, critical thinking skills allow learners to go beyond retaining information, and instead, gain a deeper understanding of the material presented to them. This deeper understanding can result in better academic performance, as well as the development of problem-solving and decision-making abilities that are essential for success in the classroom and beyond.

Critical thinking skills are essential for learners to succeed academically and in their future careers. It involves the ability to think logically, evaluate arguments, and make decisions. Critical thinking as a systematic process that provides opportunities for learners to formulate and evaluate their own beliefs and opinions. [1] Facione suggests that critical thinking skills are

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a directed, precise, and reliable thinking process in making decisions. [1] Developing strong critical thinking skills is essential for learners to become effective leaders, problem solvers, and lifelong learners who are able to navigate the complexities of the modern world. One of the evidences is the low quality report card scores of SMP Negeri 1 Peureulak, especially in the learning innovation section and critical thinking skills, besides that the results of interviews with class IX subject teachers found low motivation to learn in class this is because the learning model used by teachers is still conventional and monotonous.

The development of critical thinking skills has been a focus of education for a long time, with various models and approaches proposed to achieve this goal. According to the literature, a key aspect in fostering critical thinking is the use of diverse teaching methods and techniques that can cater to the different ways learners process and interact with information. This suggests that a universal approach to teaching critical thinking may not be enough, and educators should implement a variety of strategies to meet the diverse needs of learners [6]. [6]. [Effective learning motivation includes various characteristics that can foster the cultivation of critical thinking skills in learners [8]. Critical thinking, as an important component in education, involves the application of cognitive skills and techniques to increase the likelihood of achieving desired outcomes [2]. One crucial aspect in learning motivation is the role of the environment in encouraging critical thinking.

Developing critical thinking skills is an important aspect of education, as it enables learners to effectively analyze, evaluate and solve complex problems. However, research has found that programs designed to improve critical thinking skills are often ineffective. One potential solution to this challenge is the implementation of cooperative or innovative learning approaches, which may have a significant impact on the development of critical thinking skills. Learning motivation plays an important role in shaping an individual's cognitive development, particularly in the realm of critical thinking. Critical thinking, defined as the ability to use evaluative cognitive skills and strategies to increase the likelihood of desired outcomes, is a highly sought-after skill in educational and professional fields.

Project-based learning (PjBL) is recommended as one of the learning models in Curriculum 2013 in Indonesia, as it can improve learners' 21st century skills, including mathematical abilities [8]. However, the implementation of this model faces several challenges, such as teachers' difficulties in mastering the project-based approach and managing time effectively. In addition, research on the impact of Project-Based Learning in mathematics education is limited, with mixed findings. Some studies have reported the effectiveness of this model in improving learners' math skills [8], while other studies found no significant difference compared to traditional teaching methods.

Based on the premise that greater exposure to the STEAM class project might encourage learners to reject the stereotype that the PjBL learning model in STEAM class cannot improve critical thinking ability in upper and lower learning motivation groups simultaneously, this study aims to explore and analyze the effect of critical thinking ability based on learning motivation after they are exposed to the project. In the STEAM class project, we examined the extent to which the STEAM class project affected the achievement of high and low learning motivation groups in their critical thinking ability. We hypothesize that there is an influence between learning model and critical thinking ability, there is a significant influence between learning motivation and learning model on critical thinking ability after being taught by doing STEAM project.

2 Method

These STEAM activities are integrated with project-based teaching proposed by Arends [15] because the process of critical thinking skills is more important than the final product for learning concepts while solving problems [16]. PjBL learning models that involve fundamental questions, designing product plans, developing manufacturing schedules, monitoring project activity and progress, testing results, and evaluating learning experiences can also be integrated into all stages of project-based learning.

In this research, learners get real-world problems that require them to do direct activities with the engineering design process by designing, building, and testing a miniature model of the peureulak bridge made of 4D Frame +BS media as their project. 4D Frame+BS media is a media made from broom sticks as a substitute for 4 Frame media made from plastic pipettes originating from South Korea, where this media is more environmentally friendly and stronger against load and pressure and has a more flexible structure so that it is easier to shape and use than the original 4D Frame media [3]. The design of the peureulak bridge varies according to the image of the bridge they choose as a solution and the size of the vehicle that will pass through it. It is used as a STEAM project for the following two reasons. First, several studies have been conducted to specifically investigate topics that require spatial ability and mathematical critical thinking for geometry modeling. Second, the dynamic miniature model of the peureulak bridge supports learners' diverse ideas as they model any kind of geometric construction. The variety of peureulak bridge models stimulates learners' creativity in designing geometry modeling and creates creative critical thinking skills related to mathematics.

The main problem raised in this STEAM project is "How to design a peureulak bridge that produces a strong, balanced and durable bridge construction?". In answering this question, learners need to conduct a field survey by observing the existing Peureulak bridge with the assumption of the same conditions. Learners must have an understanding of how to calculate the strength, balance and durability of bridges through various soil conditions, strong river currents, vehicle loads that pass through them. Therefore, a series of lessons on the concept of finding equations and quadratic functions and various forms of basic knowledge are given to meet these needs.

The design and manufacture of the miniature peureulak bridge can be viewed from all aspects, science, technology, engineering, art and math. Work by Kern et al.[17] also previously reported that the culturally STEM activity of designing a fish trap (another variant of a fishing device) provided a useful assessment opportunity for the Fish Trap Challenge activity that allowed a link to math assessment. Therefore, the idea of designing a miniature peureulak bridge would also fully embody aspects of the five STEAM disciplines, as detailed below:

Science - In this activity, learners should demonstrate an understanding of density, buoyancy (when determining whether the supporting foundations should be installed with ballast), and the location of the river current where the bridge should be installed (learners should know the characteristics of the river current and target soil conditions and how they adapt to the existing ecosystem).

The technologies used in this idea involve 4D Frame+BS media [3] (i.e., learning media tools) to create learner-owned designs rather than using plastic 4D Frames. The technology also integrates the use of the geogebra application and the internet to search for bridge images as a solution and design different types of bridge model images using the geogebra application. Before using 4D Frame+BS media. Learners actively utilize the geogebra application to work together in their groups to design the design and make the miniature in 4D Frame+BS media then present the results.

Engineering-The engineering aspects are demonstrated to each group, given the 4D Frame+BS media kit, designing and modeling different miniature bridges. Learners must solve a given problem, namely: How to design what peureulak bridge that produces a strong, balanced and durable bridge construction.

Art - The art aspect is realized by each group creating a miniature bridge design as a product to be marketed. Learners need to consider how their design works so that customers are willing to pay more for the product because the design looks and feels better than other groups' products.

Math - Each group needs to perform and validate the calculation of how much durability and balance of the bridge they can create with the given material specifications. The main goal set by all groups is to create a miniature peureulak bridge that can withstand many vehicles passing over it by considering the geometry structure of the bridge.

One way of integrating STEM in learning suggested by Stohlmann [14] is by focusing on open-ended problems through engineering design challenges. The peureulak bridge project reinforced aspects of the engineering design process in this study. The environmental conservation aspect of this traditional technology also supports the low motivation group's interest in human-centered innovations relating to the human condition [10,12].

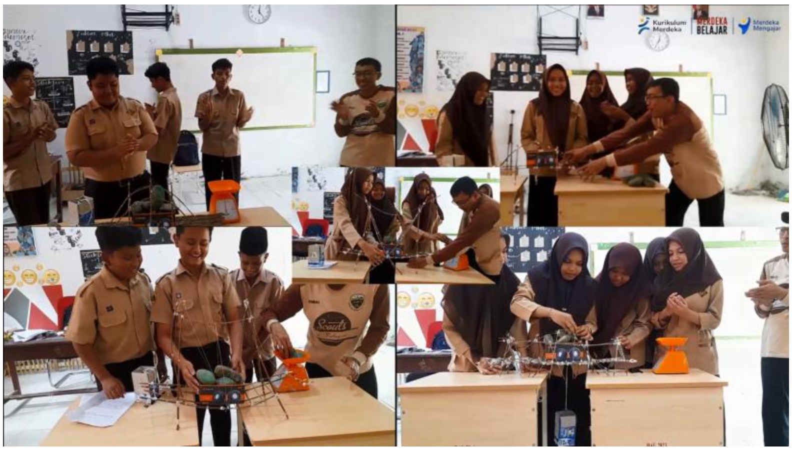

Fig. 1. 4D Frame+BS media product trial on bridge project (source: courtesy of the author)

Learners were asked to complete a critical thinking skills test on the concept of quadratic equations and functions given at the beginning and end of project-based learning with the STEAM approach. The data reported here comes from two classes, 30 learners of class IX.1 as the experimental class and 30 learners of class IX.2 as the control class in the academic year 2023/2024 in one of the public schools in Peureulak. In the experimental class, the high motivation group consisted of 15 learners compared to 15 learners in the low motivation group. This quasi-experimental research involved learners to design different shapes of traditional technology bridge miniatures as their STEAM project, such as box-shaped, curved graph-shaped, semicircular, rectangular, and combination-shaped bridge miniature models. Mathematics assessment in the context of critical thinking skills in STEAM classroom activities as proposed by [4]. [13] is used in this study, especially in assessing based on indicators of critical thinking skills.

Learners' critical thinking skills after doing the STEAM class project were documented using a critical thinking skills test. This test was constructed by the author in the format of a description math problem. It consists of several open-ended questions (some of which are taken from mathematics questions derived from end-of-semester exam questions, which are adjusted to the material at that time) which are divided into four contexts based on the concept of quadratic equations and functions. Mathematical problems and categories adjusted to the indicators of critical thinking skills [4] were used to design the test questions. The indicators of the questions in the math critical thinking ability test are as follows: (1) interpret, (2) analyze, (3) evaluate, and (4) differentiate. learning motivation indicators used consist of four indicators including: Attention, Relevance, Confidence, and Satisfaction. The motivation questionnaire consists of 35 closed questions in the form of positive and negative questions. The reliability index of the critical thinking ability instrument is 0.956 for validity analysis and the average difficulty index of each is valid and the difficult category is 2 questions, the medium category is 3 questions. While the reliability index of the learning motivation questionnaire instrument is 0.977 for the validity analysis of each is valid. This test is assessed in accordance with the predetermined assessment scheme and assessment procedures. The validity of learning instruments is carried out in two ways, namely logical and empirical validity, logical validity is carried out by 5 validators to validate related to the construction or building of instruments prepared by researchers or teachers, in this study the validators came from 2 SMPN 1 Peureulak math teachers and 3 UNIMED lecturers. In empirical validation is validation that simple language must be tested on samples or students before being used in research, the tests used are; validity test, reliability, difficulty level, distinguishing power of instruments from empirical aspects.

Learners' performance was measured using pretest scores (initial mathematical ability scores), posttest scores (critical thinking ability scores) and learning motivation questionnaires. Two-way anova test analysis was used to answer the questions "(1) Is there an effect of Project Based Learning learning model with STEAM approach assisted by 4D Frame +BS on students' critical thinking ability? (2) Is there an effect of learning motivation on students' critical thinking ability? (3) Is there an interaction between learning model and learning motivation on students' mathematical critical thinking ability?". The two-way anova test uses the SPSS 29 application and calculations manually or with the Excel application. The results of the analysis are used to get answers to the three questions. Meanwhile, if questions one, two and three are proven, a further test will be carried out to measure the size of the interaction. This was used to confirm the effect of the intervention (i.e., STEAM class project or regular learning) on learners' acquisition of critical thinking skills among the high and low motivation groups.

3 Result and Discussion

The results of the study in the form of quantitative data from the calculation of the results of critical thinking skills of the experimental class and control class, questionnaire data on learning motivation of high and low groups in experimental and control classes. In addition to quantitative data in this study there is also qualitative data in the form of descriptive data from the author's observations during the research.

3.1 Quantitative Research Results

Based on the results of research using SPSS 29, manual calculations and Excel applications between the independent variables of learning models and learning motivation on the dependent variable of mathematical critical thinking ability of junior high school students, the research results show that: (1) There is an effect of the Project Based Learning learning model with the STEAM approach assisted by 4D Frame +BS Media on students' critical thinking skills, (2) There is an effect of the Project Based Learning learning model with the STEAM approach assisted by 4D Frame +BS on students' learning motivation, (3) There is an interaction between the learning model and students' learning motivation on students' mathematical critical thinking skills. Analytical data as shown in the following table.

Table 1. Two-way ANOVA Hypothesis Test Results

Source of Variation	Dk	JK	RJK	Fo	$F_{tabel\ (0,05)}$
Between A	1	1601,667	1601,667	38,884	4,01
Between B	1	4681,667	4681,667	113,659	4,01
AB Interaction	1	375	375,000	9,104	4,01
Dalam	56	2306,667	41,190		

Based on table 1, the hypothesis of this study is proven and because the third hypothesis is also proven, further tests are carried out to measure how much the interaction between learning models and learning motivation on critical thinking skills. The results of the main effect and interaction effect are as follows: (1) Main Effect Conclusion (A): The mathematical critical thinking ability of students taught with the PjBL Learning model is higher than students taught with the Ordinary Learning model, (2) Main Effect Conclusion (B): The critical thinking ability of students in the high learning motivation group is higher than students in the low learning motivation group, (3) Conclusion Interaction Effect (AB): There is an interaction effect between learning models and learning motivation on students' critical thinking skills. Then proceed with further hypothesis testing with t-dunnet test statistics so that the following results are obtained: (1) The mathematical critical thinking ability of students taught with the PjBL Learning model is higher than that of students taught with the Ordinary Learning model, for the High Motivation student group, (2) The mathematical critical thinking ability of students taught with the ordinary learning model is lower than that of students taught with the PjBL learning model, for the Low Motivation student group, (3) The critical thinking ability of students in the high motivation student group, higher than the low motivation student group, for students taught with the PjBL learning model, (4) The critical thinking ability of students in the high learning motivation student group is lower, than the low learning motivation student group, for students taught with the Ordinary learning model.

3.2 Qualitative Research Results

In addition to quantitative data analysis, there is also qualitative data based on the results of the author's observations when research activities are carried out in the form of a description of the STEAM approach to the PjBL learning model assisted by 4D Frame +BS media as follows: (1) On the first day of the cycle, students were divided into 5 groups in each class, each group of 6 students based on the results of non-cognitive diagnostic tests. The mapping of students' learning needs based on interests is divided into three parts, namely interest areas (passions), learning styles and personality. (2) Students observe a video about the peureulak bridge that is being repaired and study the material of quadratic equations and functions, using Astro Boy media (Online and Offline applications), then based on the teacher's questions given, students respond to the video. Make a miniature peureulak bridge project. (3) Teachers together with students conduct a survey to the field to make direct observations to see soil conditions, river currents, old bridge conditions and new bridges. As well as collecting data with their groups (interviews, video documentation, photos, answering LKPD based on the results of observations of the peureulak bridge, making videos of bridge observations). (4) Learners search for bridge images on the internet to find alternative bridge shapes that are in accordance with conditions in the peureulak area, then based on the images that learners can use as a basic idea to sketch the appropriate peureulak bridge plan with the help of the geogebra application. (5) Learners with their groups work on projects to make miniature bridges according to the image designs they have made in geogebra. (6) On day 2, learners make miniature arch bridges using 4D Frame +BS media according to the results of the drawings they made through the geogebra application. (7) Together with their groups, learners present the miniature arch bridge and conduct activities to test the results of the bridges that have been made. Based on the trial, many students' bridges were successful but only 1 group had high durability and strength. (8) Together with learners and teachers make conclusions and reflections related to the material of quadratic equations and functions. (9) Learners work on evaluation questions based on the material of equations and quadratic functions to measure critical thinking skills.

Learning motivation (activeness) in addition to using a motivation questionnaire is also seen during research activities based on indicators of student learning motivation as follows: (1) Many students have begun to actively observe the video displayed on the infocus, many students' questions are given to the teacher based on the video (Attention, Relevance). (3) When students study Astro Boy media, they seem attentive and focus very much on the media (Attention, Relevance, Confindence, Satisfaction). (2) When making observations to the Peureulak Bridge, many students actively move to interview sources, take data in the form of photos, video recordings and fill in the LKPD sheet for bridge observation (Attention, Relevance, Confindence, Satisfaction). (3) Each group confidently presented the results of their bridge project with 4D Frame+BS in front of the class (Attention, Relevance, Confindence, Satisfaction). (4) Learners are no longer awkward and shy to ask questions, they help their group mates to ask questions. Confidently, each group made a miniature peureulak bridge according to the sketch they made (Attention, Confindence, Satisfaction). (5) At each stage, all groups focused on the 4D Frame+BS media project. Group 5 was very satisfied and proud when the peureulak bridge successfully passed the durability and balance test (Attention, Relevance, Confidence, Satisfaction). (6) Each group attentively watched the other group's endurance and balance tests. And asked interesting questions (Attention, Relevance, Confidence, Satisfaction).

There are some interesting findings beyond the author's prediction, as follows: (1) In the experimental class, there were 5 groups in the experimental class, but only 1 group had a peureulak bridge project using 4D Frame+BS media that had a solid bridge structure, balanced and resistant to heavy loads. However, in the assessment of critical thinking skills both at the beginning and at the end of the activity received low scores, although the results of their learning motivation questionnaire increased. (2) This is different from the experimental class of the high class motivation group, when the 4D Frame +BS project activity produced a bridge that in terms of art was good but had poor quality in terms of durability and balance against heavy loads. (3) In the experimental class, the high motivation group in the final activity in making a summary report on equations and quadratic functions material is more varied and interesting by making; video recordings, power points, info graphics, pdf and word data. While in the low motivation group only in the form of voice recordings only. (4) Of the 5 groups in the experimental class, only 2 groups had an assessment of the peureulak bridge project product using 4D Frame +BS media with good quality and some were even very strong in terms of durability and balance. However, when making the final report, the summary of the equation and quadratic function material is only ordinary. (5) In the experimental class there were students from the low motivation group who had the idea to use hot glue to strengthen the 4D Frame +BS bond besides using ropes or threads, this was very effective and useful for strengthening and making their peureulak bridge construction balanced. (6) Overall, the experimental class prefers learning activities outside the classroom using media, computers, mobile phones (gadgets), or just LKPD. This is because they are more happy, interested and try new things (based on students' comments directly). (7) In the experimental class, groups 5,4,3 although the results of the peureulak bridge project with 4D Frame +BS were not perfect, but the ability to speak and present group work in front of the class was better than groups 1 and 2 whose project results were good but the ability to present work was not smooth. (8) In the peureulak bridge observation activity, groups 5, 4, and 3 were very active both in interviewing, documenting the bridge, asking the teacher (other sources) this can be seen from the LKPD group report on the peureulak bridge and video documentation of activities when making conclusions on the results of peureulak bridge observations.

3.3 Discussion Results

Based on the results of this study, it confirms that learners experience difficulties when they face complex spatial problems, such as making a miniature peureulak bridge that must be strong, durable and balanced. However, this is not the case when the object is not complex. In addition, although the test scores of the low motivation group were lower than those of the high motivation group, the improvement was still in the high category. This shows that low motivation group learners need more effort than high motivation group learners, but it does not mean their ability is less. The concept should start from simple problems and slowly increase in complexity when presented. It was also found that the context of the questions used in the test questions affected the process of students' mathematical critical thinking ability. This finding is in line with the results of previous research that context does affect the way learners think and construct their understanding [18].

There is an influence between the independent and dependent variables with various shortcomings based on some interesting findings beyond the author's predictions, but it can still be said that the STEAM class project succeeded in developing students' critical thinking skills based on learning motivation, even the learning model also had an influence on students' learning motivation, it can be seen that there is a low learning motivation group but in the project assessment it gets very satisfying results (group 5 in the experimental class) even though the results of critical thinking skills are still unsatisfactory. STEAM projects are able to visualise shapes and spaces and provide learning experiences to create various forms of miniature bridges through this project task. The findings also show that the low motivation group working on the bridge project experienced a significant increase in learning motivation. Although not as brilliant as the high motivation group learners on their critical thinking skills scores, it is still in the high improvement category. This supports the idea that greater exposure to the STEAM class project can boost the low motivation group's learning motivation in STEAM. We argue that the STEAM class project narrowed the differences in learning motivation and had a strong influence on critical thinking skills. The results of this study complement evidence in the literature that the learning motivation gap in mathematics performance has narrowed in recent decades. The main limitation of this study is the sample size used. It cannot be generalised as the sample was small and taught by a specific teacher. However, our findings on learning motivation differences are generally in line with previous studies so it is possible that they could be repeated in a more representative sample.

4 Conclusion

This study explores the impact of using a STEAM classroom project by creating a miniature peureulak bridge to reduce learning motivation differences in the area of learners' critical thinking skills. The findings showed that the STEAM class project improved learners' critical thinking skills after the intervention, but the difference in learning motivation was significantly different. This provides empirical support that STEAM class projects can have a positive impact on both high and low motivation groups. Such STEAM projects can narrow the differences in learning motivation from secondary school age. So, this research activity provides a good opportunity to maintain learners' learning motivation, interest and academic achievement in STEAM fields because learners' attitudes towards science, preferences for specific STEAM topics, and interest in STEAM are already formed since middle school [9, 19], and even at school age. 8 or 9 years old [11].

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