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HOTS Development Strategy through Project Based STEM Learning at High School Level

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Abstract

This study aims to analyze the effect of STEM project based learning on improving students' higher-order thinking skills. The research method used is a quasi-experimental design with a non-equivalent posttest only control group design. The population of this study was all 130 students of grade XII. Then the sample was taken randomly obtained XII IPA 3 as the control class and XII IPA 4 as the experimental class. This study used test instruments in the form of essay questions and HOTS multiple choices. Data were analyzed using the SPSS program. The results of the study obtained a sig. $0.027 \leq 0.05$ meaning that the results obtained in the study were that there were significant differences in higher-order thinking skills between classes using STEM project-based learning and classes using conventional learning. Based on these results, STEM project-based learning can improve high school students' higher order thinking skills. These findings indicate that STEM PjBL can function as an effective model to improve analytical, evaluative, and creative capacity in learning in high school.

Keywords: Project Based Learning; STEM; HOTS

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INTRODUCTION

Education is a conscious effort within oneself to develop the quality of human resources. Where education is generally mandatory for all countries in the world. Teachers as implementers of learning who are part of the national education system as professionals must have four competencies, namely pedagogical, personal, social and professional competencies. To master these competencies teachers must have the ability to understand and develop curriculum and learning (Fujiawati, 2016).

Learning is the interaction between educators and students in a learning environment (Azis, 2019). Learning needs to be done to train students' thinking skills. Students must have high order thinking skills to deal with others and follow the development of science and technology in the 21st century (Fitri et al., 2018; Septikasari, 2018). Whereas in fact, high order thinking skills in Indonesia are still considered poor (Gustia Angraini, 2019; Vernando, et al., 2020) learning patterns must be changed to improve students' high order thinking skills. The learning process in educational units must be made interactive, challenging and motivating for students and students must play an active role in the learning process. In the learning process, students are given a way to find out and learn the process with a scientific approach. To encourage students to produce a work, project-based learning is needed (Kemendikbud, 2018). Another solution to improve high order thinking skills is the Science, Technology, Engineering and Math (STEM) approach to learning.

STEM education has become a popular approach among educators due to the increasing perspective of global technology in the 21st century (Shernoff et al., 2017). The STEM approach enables students to solve problems better (Sumarni & Kadarwati, 2020). The STEM approach is a way to unite science with engineering and the application of the formation of concepts and ideas from science learning. The impact of learning with the STEM approach will be more meaningful because learning will raise issues about real daily activities (Anik, 2020). In addition, STEM learning is useful for developing creative and creative thinking skills, logical, innovative and productive; instilling a spirit of cooperation in solving problems; introducing a perspective on the world of work and preparing for it; utilizing technology to create and communicate innovative solutions; media to develop the ability to find and solve problems; media to realize 21st century skills by connecting experiences to the learning process through increasing student capacity and skills; and standard technological literacy (Sirajudin et al., 2021).

Project based learning model is a learning model that involves students in problem solving, carried out individually or in groups using scientific stages with a time determined by the teacher, then the learning outcomes are expressed in the form of products and then the results are presented to others (Ariyana et al., 2018). Students in project based learning (PjBL) determine their own learning process collaboratively, students apply the knowledge they have by creating creative projects. This activity can be done through introduction to the environment, knowledge and skills using technology and then this activity can also hone students' skills and thinking abilities to analyze, evaluate and create (Dewi, 2015). The following are the advantages of the PjBL model, namely: 1) facilitating students to collaborate in conceptual understanding, applying prior knowledge, and high order thinking skills; 2) allowing students to demonstrate higher abilities; 3) challenging students to solve real problems, become good collaborators; 4) motivating students; and 5) increasing content knowledge, and meeting the needs of students with various skills and learning styles (Yustina et al., 2020). Project-based learning and the STEM approach are firmly rooted in constructivist learning theory, where knowledge is actively constructed by learners through real-world experiences, problem solving, and collaboration (AlAli, 2024; Maspul, 2024; Saad & Zainudin, 2024). In constructivist learning, students are not merely recipients of information but rather the primary actors constructing knowledge through exploration, investigation, and reflection. This model aligns with an inquiry-based learning approach that encourages students to ask questions, observe, hypothesize, experiment, and draw conclusions based on the data they find.

The collaboration of project based learning with the STEM approach is considered very suitable because both are very identical to projects (Ananda & Salamah, 2021). PjBL STEM is a collaborative learning model because participants become more involved in learning activities and groups and share knowledge to help students open up other knowledge during the thinking process (Ralph, 2011). Through reading, writing, observing, and working on projects that can be used to solve problems, PjBL STEM teaches children to think scientifically and build technical literacy processes (Lestari et al., 2018). In STEM learning, students undergo project based learning (PjBL) activities. In the implementation of project based STEM learning approaches, there is a process of thinking, designing, making, and testing. This means that when students have completed the project, the project is tested whether it is as desired or not (Dewi, 2019).

The PjBL model is applied to complex problem material where students must analyze and understand it well. As in learning basic electrical material. Efforts to improve the quality of education trained in electrical circuit material can use project based learning media STEM which has been designed and validated, namely the electrical installation prototype kit (Yennita et al., 2020). Research related to STEM projects conducted by Lestari et al., (2018) stated that learning using STEM projects can improve students' science processes and creative thinking. Furthermore, research conducted by Keleman, (2021) stated that STEM project learning can improve students' higher-order thinking skills, but this study used research subjects at the elementary school level. This study has advantages because it is specifically designed to develop students' higher order thinking skills through project activities that emphasize the processes of analysis, evaluation, and creation. The developed projects also encourage students to actively engage in solving real-world problems through a scientific approach and the integration of STEM disciplines as a whole. Thus, this study not only complements previous findings but also provides a more focused and meaningful contribution to efforts to improve HOTS through the PjBL STEM model.

This study focuses on the implementation of STEM project based learning in junior high school science learning. The purpose of this study was to describe students' high order thinking skills with the implementation of STEM project based learning on electrical circuit material and to test whether there is a difference in students' high order thinking skills in classes that implement STEM project based learning with classes that implement conventional learning. The researcher hypothesizes that STEM project based learning can improve students' high order thinking skills. The formulation of the problem in this study is (1) How are students' high order thinking skills with the implementation of STEM project based learning on electrical circuit material?; (2) Is there a difference in students' high order thinking skills between classes that implement STEM project based learning and classes that implement conventional learning on electrical circuit material?.

METHOD

This study is a quasi experimental study. This type of research is said to be quasi-experimental because in this design there are control variables but do not play an overall role in controlling external variables that can influence learning in the experimental class (Sugiyono, 2019). The research design used is a non-equivalent post test only control group design, there are two sample groups that receive different learning, namely the experimental group applied the STEM-based PjBL model while the control group with the conventional model. The population in this study was all class XII totaling 130 students. The method of determining the sample is done randomly. The characteristics of the sample in this study must be normal and homogeneous, namely the data tested do not have too much difference in terms of ability and number of subjects studied, so that there is a difference in the increase in students' HOTS abilities in accordance with the research objectives. The sample used was XII IPA 4 as many as 24 students as the experimental class and XII IPA 3 as many as 25 students as the control class. The experimental class used the STEM based PjBL model and the control class used the conventional learning model. The following is the research design:

Table 1. Research design (Hastjarjo, 2019)

Class	Treatment	*Post-test*
Experiment	X	O_1
Control	-	O_2

After being given treatment to both classes, a post-test will be given in the form of a high order thinking ability test using instruments in the form of multiple choice questions and essays totaling 8 questions according to the indicators where 3 multiple choice questions analyze, 3 multiple choice questions evaluate, and 2 essay questions create. The HOTS question instrument used in this study has been tested for validity and reliability. The test results indicate that all items are valid in terms of content and construct. Furthermore, the reliability value obtained was 0.733, which is considered high. This indicates that the instrument is reliable and consistent in measuring students' higher order thinking skills (HOTS) accurately and sustainably. Then the results obtained will be analyzed using descriptive analysis and inferential analysis.

In descriptive analysis if the average difference has a positive value, it can be interpreted that students' high order thinking skills increase with the implementation of STEM project based learning, if the average difference has a negative value, it can be interpreted that students' high order thinking skills decrease with the implementation of STEM project-based learning. Student score can be found with the following equation (Elyana et al., 2018):

$$\text{Score} = \frac{\text{score obtained}}{\text{total score}} \text{ x } 100$$

The decision-making criteria for assessing the average score of high order thinking skills can be seen in Table 2.

Table 2. Interpretation Criteria for Students' Average Score Assessment (Sugiyono, 2015)

Value interval	Category
$85 \leq x \leq 100$	Very good
$70 \leq x < 85$	Good
$50 \leq x < 70$	Enough
$0 \leq x < 50$	Not good

Then an inferential analysis was conducted by conducting an independent sample t test. Determining whether or not learning has increased after being given a treatment can be seen from Sig. The independent sample t test is used to see if there is a difference in high order thinking skills between students who apply STEM project based learning and students who use conventional learning.

RESULTS AND DISCUSSION

The research was conducted during school learning with a hybrid learning system according to government recommendations in the field of education related to the current Covid-19 pandemic situation that is hitting the world. Hybrid learning consists of two words, namely hybrid/blended which means mixed and learning which means learning, so hybrid learning or blended learning is doing mixed learning. In the place where the research was conducted, learning was carried out in a mixed manner with 50% of students studying at school and 50% of students studying at home by connecting using the Zoom application to school. Here are the STEM projects that students did:

Figure 1. Project for assembling a street light installation with a single lamp circuit

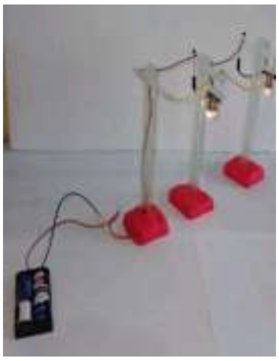


Figure 2. Street light installation assembly project

Figure 3. Project: Assembling a simple house model and installing electrical installations

Figure 4. Project for assembling electrical installations with solar cell energy sources.

In the project based learning (PjBL) implemented in this study, students were presented with real-world challenges through a series of projects ranging from simple electrical installations to renewable energy utilization. These projects were designed to integratively train higher order thinking skills (HOTS) within a STEM context.

In the first project, which is assembling a street light installation with a single lamp circuit, students learn to build a basic electrical system that functions optimally and safely. Although only a single lamp is used, this project trains students' analytical and evaluation skills regarding circuit structure, cable connection errors, and switch function in the system. This activity also brings scientific concepts such as conductivity and electrical energy closer to real-world applications. Furthermore, in the second project, which is assembling a more complex street light installation, the challenges presented are higher. Students not only build the circuit but also design the lamp layout, select appropriate materials, and calculate the required cable length and electrical load. This activity requires students to think critically and creatively in solving broader technical problems while evaluating the efficiency and effectiveness of the lighting system they create. This activity is highly relevant in developing systematic thinking and solution oriented skills as part of 21st century skills. The third project, which involved assembling a model house and installing its electrical components, provided a more contextual learning experience. Students not only creatively built miniature houses from simple materials but also had to design the electrical system in each room. This project encouraged logical and structured thinking, from switch placement and light distribution to circuit safety. This activity built students' comprehensive understanding of science, technology, and engineering concepts through hands on experience, while also enhancing their evaluative thinking and creative design skills. Finally, the fourth project, which involved assembling a solar cell based electrical installation, encouraged students to understand and utilize alternative energy as an environmentally friendly solution for the future. Using solar panels as a power source, students learned how solar energy is converted into electricity and how its storage and distribution systems are designed. This project trained students in observation, interpretation of light intensity data, electrical power analysis, and system efficiency evaluation. This activity fostered environmental awareness while developing higher order thinking skills such as innovation, synthesis, and evidence based reasoning.

Overall, the four projects not only provide students with ample scope for exploration but also encourage them to integrate knowledge across disciplines of science, technology, engineering, and mathematics to solve problems. These projects have been shown to improve HOTS indicators, such as the ability to analyze, evaluate, and create, while also strengthening scientific literacy, namely explaining phenomena scientifically, interpreting data, and using scientific evidence in decision making.

After conducting science learning with STEM project based learning in class IX.3 and conventional learning in class IX.4, the following descriptive data analysis results were obtained.

Table 3. Description of the Number of Students Based on HOTS Test Results

Score	Category	Control Class		Experimental class	
		n	%	n	%
85< x <100	Very good	0	0	5	20
70< x <84	Good	1	4.17	2	8
50 ≤ x < 69	Enough	5	20.83	6	24
0 ≤ x < 49	Not good	18	75	12	48
Total		24	100	25	100

Based on Table 3, it can be seen that the distribution of students who have high order thinking skills in classes that use STEM project based learning is greater. In the results obtained, students who have high order thinking skills in the experimental class with a very good category are 20% of students, while compared to the control class, there are no students who have high order thinking skills in the very good category. The difference in the average value between the experimental classes is 16.03. So based on the decision making criteria, the average difference produced in this study has a positive value, so it can be interpreted that students' high order thinking skills increase with the implementation of STEM project learning.

In this study, the data obtained were analyzed using inferential analysis applicable to the population. A conclusion from sample data applied to the population has a chance of error and truth in the form of a percentage (Sugiyono, 2015). Based on the results of the independent t test conducted with the help of the SPSS statistic 23 application which can be seen in Appendix 11 for hypothesis testing, the significance result was $\rho = 0.027$ with a confidence level of 95% and an average difference between the two classes of 16.02917.

Hypothesis testing was conducted to determine whether there was a significant difference between STEM project based learning and conventional learning. Based on the t-test conducted to test the hypothesis H0 where the posttest output results of the independent t-test obtained were $t = 2.279$, the significance value $\rho = 0.027$. Based on the criteria for drawing conclusions from the t-test, the results obtained were $\rho < 0.05$, so it can be concluded that there is a significant difference in high order thinking skills between classes using STEM project based learning and classes using conventional learning.

In classes that use STEM project based learning, students' high order thinking skills are classified as quite good and in classes that use conventional learning, students' high order thinking skills are classified as less good. This is in line with research that reveals that students' high order thinking skills are classified as low (Sara et al., 2020). This is because students are not used to the high order thinking skills questions given. According to Kusuma et al., (2017), most of the questions used as assessment instruments in Indonesian schools tend to test memory aspects more, while questions to train high order thinking skills are not widely available.

The experimental class obtained higher results than the control class. This is because STEM project based learning requires students to be more active in experimenting and in learning students are also trained in the ability to analyze, evaluate and create. According to Niswara et al., (2019) that project based learning can affect students' high order thinking skills compared to classes that receive conventional learning. The results of data analysis on high order thinking skills, namely with indicators of the level of analysis (C4), the level of evaluation (C5) and the level of creation (C6) through STEM project based learning, can be explained based on Figure 5.

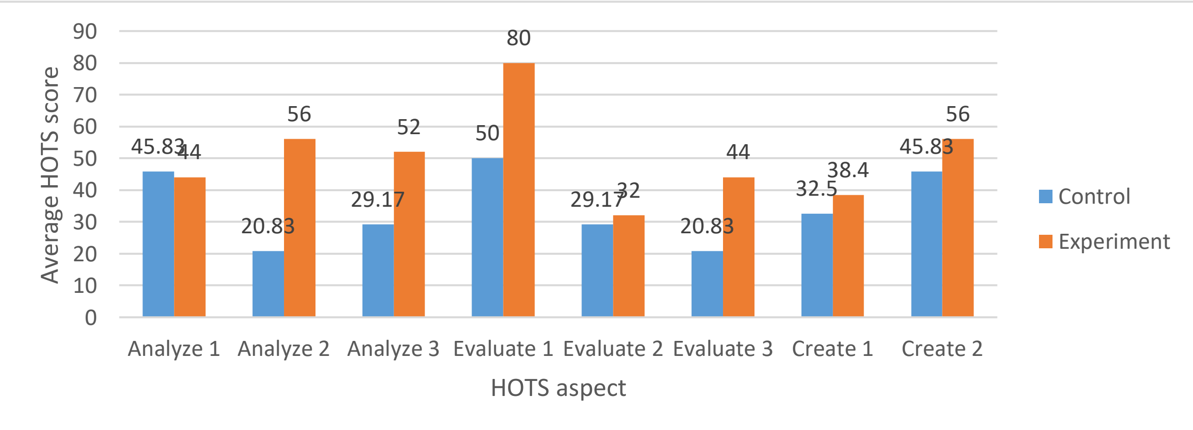


Figure 5. Average value of students' HOTS abilities per indicator

Based on Figure 2, it can be seen that overall the average value of high order thinking skills of experimental class students in all questions is higher than the control class except for the indicator of analyzing the first question. Based on the graphic image, it can be seen that there are three indicators of high order thinking skills, namely analyzing, evaluating and creating.

Analyze

Analyzing is an activity that involves parts and structures in the thought process to solve a problem. Analyzing involves the process of analyzing, distinguishing, organizing and attributing(Rochman & Hartoyo, 2018). In the high order thinking ability test questions given, there are three questions that have analytical indicators.

Based on the results obtained from the second question which had the theme of Ohm's law in parallel circuits and the third question which had the theme of current strength and voltage in combined circuits, the average value for the experimental class was higher than the control class. This is because in the experimental class during learning students are trained how to analyze and find the relationship between current and voltage in series parallel circuits using a virtual lab. And with the STEM projects given, students play an active role and are trained to analyze how to assemble and contribute or interpret things that occur in parallel circuits. According to Rochman & Hartoyo (2018) that by training students' ability to attribution, students can connect the causes and effects that occur.

Getting students' brains used to working by involving students in activities in analyzing, evaluating and creating will make it easier for students to train HOTS within themselves (Rochman & Hartoyo, 2018). According to Sawitri et al., (2015) that efforts to improve analytical skills are by implementing appropriate learning models and learning media.

The first question had the theme of analyzing Ohm's law in series circuits. The experimental class got a lower average score than the control class, with the average difference being 1.83. In this ability, researchers have tried to hone students' analytical skills by involving students in analyzing the relationship between voltage and current strength with the help of virtual labs in learning. This is caused by students' lack of understanding of the ohm's law formula in understanding the question instructions given. According to Gustia Angraini (2019) that students have difficulty understanding and translating questions. Overall, it was found that the average score for the high order thinking abilities of experimental class students was better than that of the control class. The form of the analysis indicator questions is as follows:

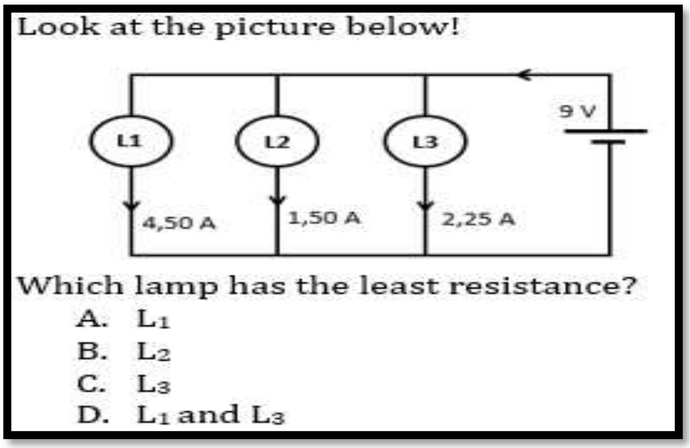


Figure 6. Analysis questions (C4)

This question model measures the ability to analyze the concept of parallel circuits by asking students to compare resistance values based on current and voltage data using Ohm's law principles in an applicable and contextual manner.

Evaluate

Evaluating is an activity carried out by students to determine the right solution from the existing choices, criticize something and check whether something is running according to the provisions or not. In the high order thinking ability test, there are three questions that have evaluating indicators, namely the fourth, fifth and sixth questions.

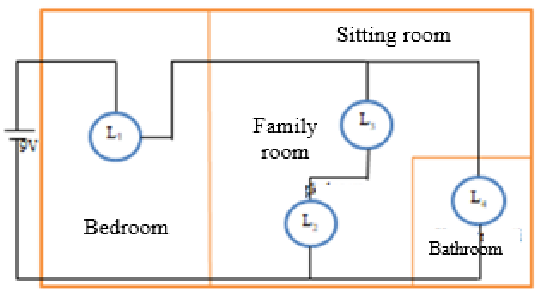
All questions that have evaluation indicators for the experimental class are higher than the control class. In this indicator, students are required to be able to determine and criticize the choice that best fits the narrative given, where the questions given are related to the sub topics studied in electrical circuits, namely energy and power and alternative energy sources. According to Sularmi et al., (2018) that project based learning can create a good learning environment, increase students' active role in learning and students learn to develop ways to solve and criticize problems and improve students' thinking abilities.

The fourth question is a question with the theme of alternative energy sources. Where students are given a statement and students determine whether the statement is true or not. On this question, experimental class students got the highest average score compared to the others. This is because the fourth question contains evaluation questions found in everyday life, so that it is easier for students to evaluate. This is in line with study Sari et al., (2017) that completing HOTS will be more complex and in accordance with the experience each student has.

The value of this fourth question also has a difference between the experimental class and the control class. This is because in the experimental class students are given a solar cell where students have practiced and know that if the incoming light is brighter, the energy obtained by the solar cell will be large and the light will light up brighter. Meanwhile, in the control class, students did not get this experience.

All the average values of the experimental class in the evaluating category are above the control class. This is because the experimental class created a STEM project which was given so that the students who worked on the project were trained to evaluate the causes of bright lights in electrical circuits and the factors that support the existence of alternative energy sources. When students solve a problem, students must be able to identify the problem, then continue by analyzing one part with another. This will determine the ability to think further, if students do not have good analytical skills, then students will have difficulty evaluating and creating.

Mr. Amir designed a simple home electrical installation. He wanted the bedroom light to shine brighter than the other lights. He used four identical lamps with the same design as shown in the image below.



Is Mr. Amir's electrical installation design correct?
A. Correct, because Lamp 1 carries the greatest current.
B. Incorrect, because Lamp 4 is the brightest.
C. Incorrect, because all four lamps have the same wattage.
D. Correct, because Lamp 1 is closest to the voltage source.

Figure 8. Evaluating Questions (C5)

However, the results obtained in this study, the average value of the experimental class on the evaluation indicators was higher than the analyzing indicators. This could be caused by students' interest in the topic of alternative energy sources being higher than analyzing Ohm's law in series parallel circuits. Analyzing series parallel circuits contains a process of applying mathematics in it so that students think the problem is more difficult. So when learning series parallel circuits, student motivation is not good. According to Pujiastuti in Amalia & Pujiastuti, (2020) that student learning motivation is directly proportional to student learning outcomes. So when students think about questions that have difficult numbers, students' learning motivation will decrease. The following is one form of question from the evaluation indicator used in this research.

This question measures students' understanding of the effect of the position of the lamp in a parallel circuit on current and brightness, as well as their ability to analyze the relationship between power, current, and distance to the voltage source.

Create

In the creating indicator, students are expected to be able to create a design based on the provisions provided by the question. In the high order thinking ability test, there are two questions that contain indicators of creation, namely questions seven and eight, where the questions have the theme of using alternative energy and designing automatic light circuits.

In the two questions that have indicators, the experimental class has a higher average value than the control class. In the seventh question the experimental class was categorized as poor and in the eighth question the experimental class was categorized as quite good. This is because in classes that are given STEM project based learning, students are used to being trained to think about creating or designing something, so that when they are given questions with the domain of creating indicators, it will be easier for students to digest them. This is in line with research conducted by Amalia & Purwanto (2017) that the project based learning model can improve high order thinking abilities in the ability to create (C6). One of the forms of creative questions used in this research is:

> Design a bedroom lamp that automatically turns on when someone is present and automatically turns off when no one is present. Then, briefly explain how it works.

Figure 9. Creating Questions (C6)

This question is included in the creative category (C6) because it requires students to design an original solution in the form of a sensor based automatic lighting system, while explaining how it works logically and functionally according to the principles of science and technology.

The findings of this study align with Vygotsky's Zone of Proximal Development (ZPD) theory, which states that students are able to achieve higher levels of cognitive development when supported through social interaction and scaffolding. In the context of PjBL STEM learning, students do not work individually but are guided by teachers and peers through discussion, collaboration, and real world problem solving, enabling them to go beyond their own capabilities. The STEM projects used in this study serve as a strategic vehicle for fostering this contextual shift, strengthening knowledge transfer, and deepening students' higher order thinking skills on an ongoing basis.

CONCLUSION

Based on the research conducted, the average grades of classes implementing STEM project based learning are categorized as sufficient and the average grades of classes implementing conventional learning are poor and the difference in average grades of the experimental class and the control class is positive. There is a significant difference in students' higher order thinking skills between classes implementing STEM project based learning and classes implementing conventional learning. Therefore, it can be concluded that STEM project based learning can improve high school students' higher order thinking skills. The implementation of project based STEM should be designed contextually and relevant to students' real lives. Teachers need to guide students to think critically and creatively through collaborative activities. School support, teacher training, and adequate time are crucial for the success of this project based learning. Although useful, this model requires adaptation to various classroom contexts and further validation through longitudinal or mixed methods studies.

RECOMMENDATION

The recommendation for future research is to develop a more structured and adaptive project based learning strategy that aligns with the characteristics of high school students, incorporating deeper interdisciplinary integration within the STEM approach particularly in real life contexts relevant to students' environments. Further studies are also encouraged to expand the sample scope and apply mixed methods approaches to explore the qualitative aspects of HOTS development. Potential challenges may include limited time for project implementation within the regular curriculum and insufficient supporting facilities at schools, which may require researchers to provide the necessary resources during the implementation of the learning process in the study.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state that they have no conflict of interest related to the research, authorship, or publication of this article.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

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