

Enhancing Pre-service Physics Teachers' Higher-Order Thinking Skills Through STEM-PjBL Model

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Abstract

This study aimed to determine the higher-order thinking skills of pre-service teachers through STEM-PjBL Model. The research method used was a quasi-experimental with one group pretest-posttest design. The N-Gain results mention the N-gain in both experimental and control classes that the physics learning process through the STEM-PjBL Model is 21% higher in improving higher-order thinking skills than Direct Learning. Improvement of students' ability to solve HOTS categorical questions in the experimental group taught by applying STEM-PjBL Model scored N-Gain 75% or 0.75, which increases the high category. In comparison, the control group led by applying the Direct Learning model achieved 54% or 0.54, meaning a moderate increase in categories. The results showed that learning using STEM-PjBL Model could improve higher-order thinking skills more than Direct Instruction Learning. The implications of this research include: gaining new knowledge that can be used as a pre-service teacher', adding insight regarding STEM-PjBL Model that can be used to grow students' science process skills, assisting schools in improving the quality of students, and the quality of the physics learning process in schools.

Keywords: STEM-PjBL Model, Higher-Order Thinking Skills, Physics Education, Pre-service Physics Teacher

INTRODUCTION

The 21st century offers a life in a frameless world where the flow of globalization, internationalization, technology development, information, and communication are increasing rapidly (Mcgrath & Fischetti, 2019). This development impacts science development, and one aspect affecting it is education (Pujiastuti et al., 2020). However, indirect actions in the 21st century also affect the dynamics of education today (Medvedeva, 2015; Ongardwanich et al., 2015). The 21st century requires students to develop their skills actively so that knowledge is expected to equip students to find scientific concepts such as scientists in a limited scope to solve problems faced and anticipate issues that may arise in the future (Pujiastuti et al., 2020). 21st-century skills that students must possess are higher-order thinking skills (HOTS) (Ichsan et al., 2019).

HOTS occurs when a person links new information with previously stored information in his remember and relates it, or recombines and develops knowledge to attain a goal or solve an issue (Sutarto et al., 2018). Students are required to have HOTS to prepare critical and creative human resources to meet the challenges and demands of the 21st century, which are also called

the global era or the era of knowledge or the age of technology and information (Yee et al., 2015). The better a person's HOTS, the better his ability to develop strategies and tactics to win a free competition in the global era (Vidergor & Krupnik, 2015).

HOTS in the cognitive processes dimension is divided into six categories: remembering, understanding, applying, analyzing, evaluating, and creating. Thinking skills are classified into two levels, namely lower-order thinking skills consisting of remembering (C1), understanding (C2), application (C3), and higher-order thinking skills consisting of analyzing (C4), evaluating (C5), and creating (C6) (Magas et al., 2017). For more details, it can be seen in Figure 1 below.

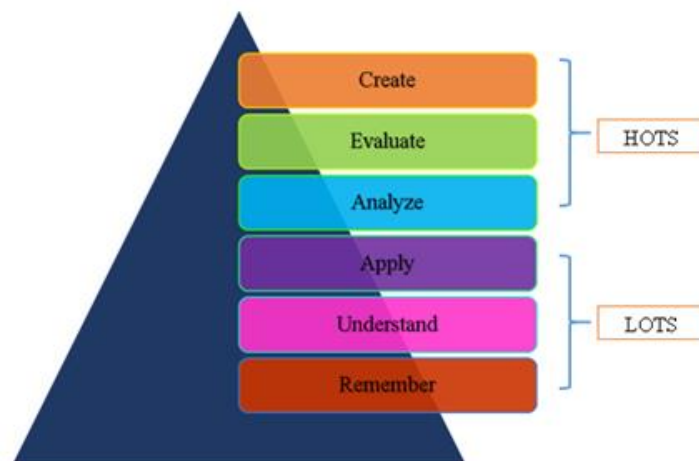


Figure 1. Dimensions of HOTS

Based on Figure 1, HOTS requires a more complex thinking process including application, analysis, evaluation, and creation which is supported by the ability to understand, so that: (1) able to think critically; (2) able to provide logical, systematic, and analytical reasons; (3) able to solve problems quickly and precisely; (4) able to make decisions rapidly and accurately; and (5) able to create new products based on what has been learned. Thus, to develop HOTS, it must already know and remember it and understand it (Dubas & Toledo, 2016).

HOTS is an important thing that can be applied in the learning process, including physics learning (Istiyono, 2017). Physics is one of the most basic science branches and underlies other branches of science (Koponen & Huttunen, 2013). That is why physics is widely applied in other sciences. Physics is an experimental science used to find patterns and principles that connect natural phenomena (Haryadi & Pujiastuti, 2019). Physics is a branch of study that investigates natural phenomena and occurrences in inanimate objects objectively, logically, methodically, and rationally using scientific procedures and attitudes (Haryadi, 2019). Physics is a science that can foster students' thinking abilities that are useful for solving problems in everyday life (Haryadi & Pujiastuti, 2020b). The application of higher-order thinking skills in

physics learning will result in students accustomed to analyzing, reasoning, and being creative in solving problems in life (Kusuma et al., 2017).

Higher-order thinking skills occur when students are involved with what they know in such a way as to change it, meaning that students can change or create the knowledge they learn and produce something new (Saritepeci, 2019). Students will be able to differentiate concepts or ideas more clearly, debate successfully, solve issues, develop explanations, speculate, and grasp difficult things more clearly using higher-order thinking skills (Miri et al., 2007). Higher-order thinking skills include information transfer, critical thinking, and problem-solving (Jensen et al., 2014). Learning to transfer is meaningful learning because students can apply their knowledge and skills and associate information with each other (Pujiastuti & Haryadi, 2020). There is also learning by critical thinking so students can argue, reflect, and make their own decisions (Lee & Choi, 2017). Problem-based learning aims to identify and find solutions to problems both academically and in everyday life (Haryadi & Pujiastuti, 2020). The HOTS question, when seen from the knowledge dimension, often examines the metacognitive extent, rather than merely the factual, conceptual, or procedural dimensions (Roets & Maritz, 2017). The metacognitive tests assess the capacity to link several concepts, understand, problem-solve, adopt a problem-solving approach, discover new ways, debate, and make the best judgment (Primi et al., 2020).

HOTS is one of the essential competencies in the modern world, so it is a must for every student (Amzat & Valdez, 2017). Higher-order thinking skills can be trained in the learning process in the classroom (Doolen, 2015). Therefore, to think at a high level, the learning process also provides space for students to find the activity-based knowledge concepts (Nguyễn & Nguyễn, 2017). Activities in learning can encourage students to build creativity and critical thinking (Lee & Choi, 2017). Higher-order thinking skills have been investigated, and the research subjects were 51 students of the Israel Institute of Technology (Barak & Judy, 2009). The research was conducted by forming a Journal Club course with class discussion activities. This study found that students' higher-order thinking skills can be seen from complex questions, provide opinions, provide consistent arguments, and demonstrate critical thinking.

Research related to higher-order thinking Was also conducted, the subjects of this study were 15 Engineering students at the International University in Malaysia (Vijayaratnam, 2012). This study uses a mixed-method with the interview techniques, observation, document analysis, and final evaluation. The result of this study is that group problem solving can effectively develop higher-order thinking, problem-solving, and student collaboration. Higher-order thinking in learning physics is studied. The research subjects were 393 Benguet State University

students, with 112 males and 281 females. The HOTS aspects studied were analyzed, compared, inferred, and evaluated. This study states a significant relationship between higher-order thinking skills and male and female students' physics performance—the HOTS level on analyzing, comparing, and evaluating. Significantly influences male students' physics performance. The HOTS level of analysis, create, and evaluation significantly affects the physics performance of female students (Nguyễn & Nguyễn, 2017).

The problem found is that there are still many students who have not been able to understand the concept of physics well. It is suspected that there is a relationship between students' low higher-order thinking skills in analyzing an event and the learning process that has been applied so far. The low higher-order thinking skills occur because learning does not reach them, giving rise to the assumption that physics is not useful in everyday life, especially to face challenges in the 21st century.

Higher-order thinking skills begin to grow and form along with habits that are carried out and practiced continuously. Students often have difficulty when faced with activities that require students to think creatively. Therefore, it is necessary to actively improve the learning process to bring up science process skills in physics subjects.

One way to overcome this is by carrying out projects or practical learning activities. Project-based learning (PjBL) can be one of the learning solutions that support improving 21st-century skills. In project learning, students are given the task of finding and developing a concept for themselves to encourage students to develop higher-order thinking skills. One of the efforts that can be done is to provide treatment. It can bring students to the optimal level of activity and creativity. The treatment in question is to apply STEM-based project-based learning (STEM-PjBL), which integrates STEM fields (Science, Technology, Engineering, Mathematics).

State of the art in this research are: (1) STEM-PjBL Model has become a popular topic in physics learning research. Numerous studies have confirmed that this improves learning outcomes and motivation to study physics. (2) Most studies on STEM-PjBL Model focus on students' overall learning outcomes. Some have explored individual differences among students. Higher Order Thinking Skills for prospective physics pre-service teachers are worth testing because they are being used to face 21st-century challenges.

Meanwhile, contributions of this research are: (1) Bringing significant results to knowledge and competence in STEM-PjBL Model. (2) The experience has a significant impact on analyzing, evaluating, and creating. (3) Increased student enthusiasm, as noted in observations during the learning process. Using the STEM-PjBL Model is recommended to

improve Higher Order Thinking Skills. While this is a small sample size, this study contributes to the literature investigating STEM-PjBL Model impact as a helpful learning model. Based on the research gap, this research aimed to determine the different effects of physics learning through STEM-PjBL Model on improving the Higher-order Thinking Skills of physics pre-service teachers.

METHOD

This type of research in this study is quasi-experimental research to describe the application of the STEM-PjBL Model, students' higher-order thinking skills, and students' responses to the performance of the STEM-PjBL Model. In this study, the research subjects are 50 pre-service physics teachers at the physics education department at one state university in Indonesia. Research subjects were first given a pre-test to determine the extent of the students' initial abilities before being given physics learning. After that, the students are given treatment, namely, physics learning using STEM-PjBL Model in the experimental class. At the same time, the physics learning control class uses direct instruction learning. Furthermore, all students are given a post-test to determine the extent of physics learning by using STEM-PjBL Model and explicit instruction learning on higher-order thinking skills. The research design used can be seen in Figure 2 below.

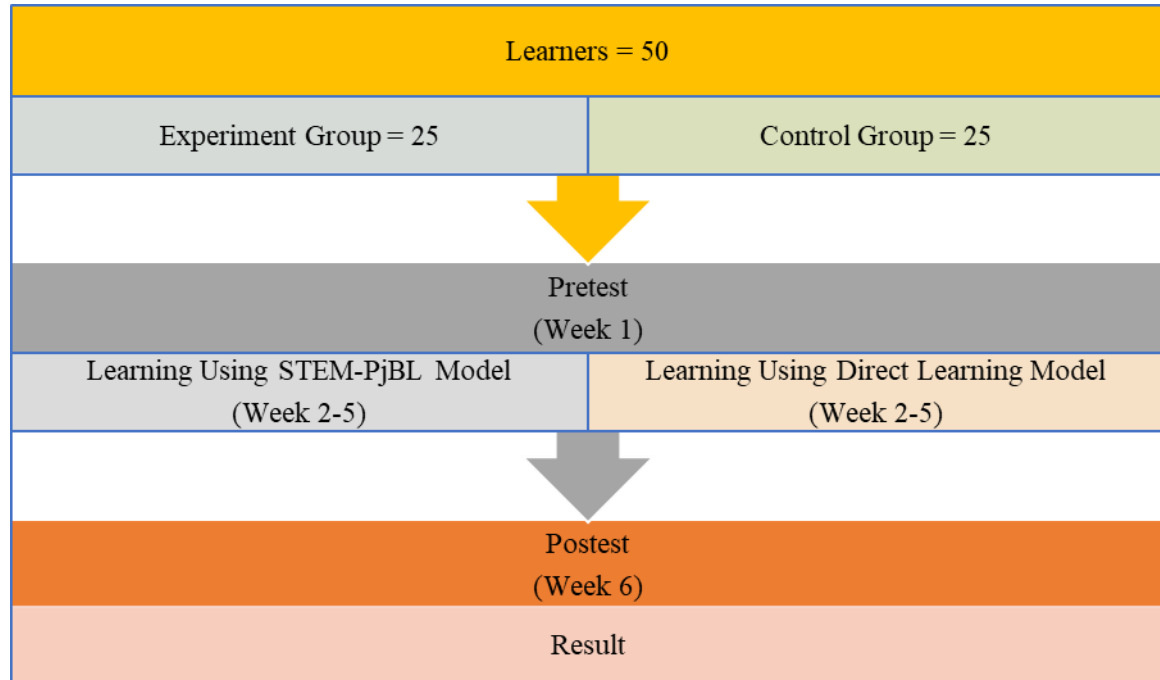


Figure 2. Experimental design

After obtaining the pre-test and post-test results, the researcher used the normalized gain score formula (N-Gain) to investigate the increasing of higher-order thinking skills. The

existence of a normalized gain score (N-Gain) provides an overview of improving students' high-level thinking skills between before and after treatment (R.R. Hake, 1999).

$$n - g = \frac{X_{post} - X_{pre}}{X_{max} - X_{pre}} \quad (1)$$

Explanation:

n-g = n-gain

X_{pre} = pretest score

X_{post} = posttest score

X_{max} = maximum score

Equation (1) is individual N-gain, and the average N-gain is calculated by dividing the number of N-gain of each individual with the number of individuals. The interpretation of N-gain is presented in Table 1 (Richard R. Hake, 1998).

Table 1. Interpretation of N-gain values

Score N-gain	Classification
$g \geq 0,7$	High
$0,7 \leq g \leq 0,3$	Medium
$g < 0,3$	Low

The STEM-PjBL Model in guiding students consists of five steps, and each step aims to achieve a specific process. The following are the stages in the effective STEM-PjBL Model.

1. The goal of the first step, reflection, is to immerse students in the context of the topic and motivate them to begin exploring right away. This phase also serves as a bridge between what is already understood and what has to be learnt.
2. The second step is research, which is a type of student research. The instructor picks literature or other means to obtain suitable sources of knowledge for scientific classes. During this stage, the learning process is more active. The advancement of the students' learning concretizes the problem's abstract knowledge. The teacher frequently steers the conversation throughout the research phase to see if students have gained a meaningful conceptual understanding based on the assignment.
3. Discovery: In the planning of a project, the discovery phase often entails connecting research and knowledge that is already available. Some STEM-PjBL Model models split students into small groups to propose various answers to issues, cooperate, and foster collaboration among friends in the group as they begin to study independently and identify what is still unknown. This stage is used in another approach to help pupils gain the capacity to form a behavior of thought from idea to design.
4. Application: The purpose of the application stage is to put products/solutions to the test in order to address problems. In other circumstances, students test items that are manufactured

under predetermined conditions, and the results are utilized to enhance the preceding phases. In another paradigm, at this level, students acquire a broader perspective outside of STEM or the connection across STEM subjects.

5. Communication, the last stage in every project in which students communicate amongst friends and within the scope of the class to create products/solutions. Presentations are a crucial part of the learning process because they help students develop communication and cooperation skills as well as the capacity to take and implement constructive criticism. The completion of the last step of this phase is frequently used as the basis for evaluation.

The Direct Learning model is a learning paradigm that promotes idea mastery and behavioral changes by stressing the deductive method, and it includes the following features (Aldallal et al., 2019): (1) transformation and direct skills; (2) learning that is focused toward specified goals; (3) structured learning material; (4) structured learning environment; and (5) organized by the instructor. Educators serve as information carriers, and in this situation, they employ a range of acceptable media, such as films, tape recorders, photographs, and demonstrations. Procedural knowledge (knowledge of how to accomplish something) and declarative knowledge are two types of knowledge that may be imparted (knowledge of something can be in the form of facts, concepts, principles, or generalizations). The model's critics argue that it can't be employed all of the time and for all students' learning needs (Holly et al., 2019; Rascón-Hernán et al., 2019; Romaszko et al., 2020). The following stages:

1. Orientation. Before presenting and explaining new material, it will be beneficial for students to provide a lesson framework and direction to deliver the material. The forms of orientation can be in the form of (1) preliminary activities to find out knowledge relevant to the experience that students already have; (2) discuss or inform the objectives of the lesson; (3) provide an explanation/direction regarding the activities to be carried out; (4) educate the material/concept that will be used, and the activities that will be carried out during the learning, and (5) inform the learning framework.
2. Presentation. In this phase, educators can present subject matter in the form of concepts and skills. Presentation of the material can be in the form of (1) expression the material in small steps so that students can master the material in a relatively short time, (2) giving examples of concepts; (3) modeling or demonstration of skills through demonstrations or explanations of work steps on the task; and (4) re-explain complicated matters.
3. A well-structured workout. Educators lead pupils with exercises in this phase. Educators' key role in this phase is to offer feedback on student replies and to reinforce both correct and wrong responses.

4. Practice with a mentor. Educators give chances for pupils to practice concepts or skills in this phase. This guided activity may also be used by instructors to measure pupils' abilities to complete their tasks. Educators' responsibility in this period is to observe and, if necessary, give guidance.
5. Self-taught. Students do the training activities on their own in this phase; students can pass this phase if they have mastered the levels of work assignments 85-90 percent of the time during the training guidance phase.

RESULTS AND DISCUSSION

Based on the results of the study, obtained data results, namely pre-test and post-test data. Furthermore, the results of higher-order thinking skills can be seen in Figure 3 below.

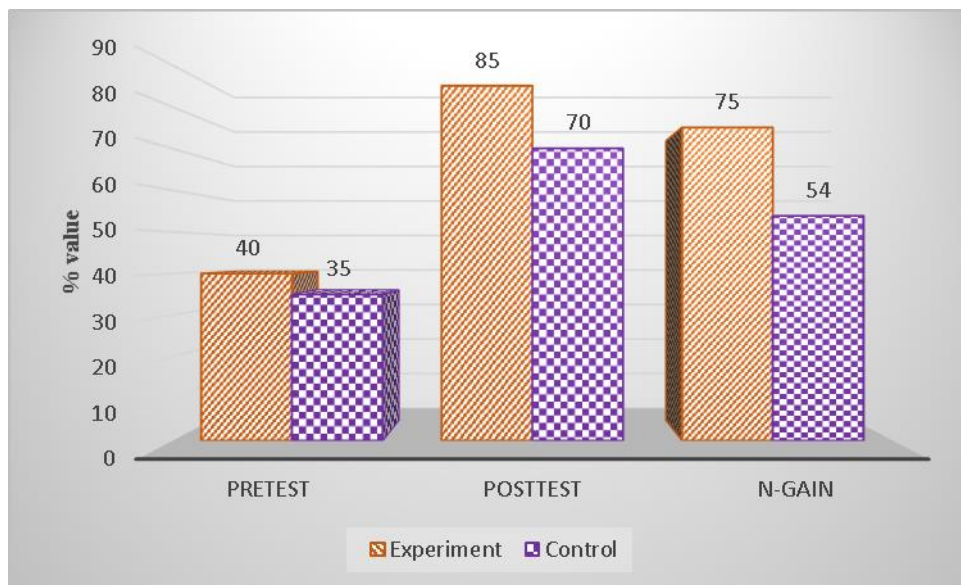


Figure 3. Graphical comparison of the average value of the pre-test, post-test and gain normalized higher-order thinking skills

Figure 3 shows N-Gain's value, which shows that the physics learning process through the STEM-PjBL Model is 21% higher in improving higher-order thinking skills than Direct Learning. Improved students' ability to solve HOTS categorical questions in the experimental group was taught by applying STEM-PjBL Model to score 75% or 0.75, which increased the high category. In comparison, the control group using the Direct Learning model achieved 54% or 0.54, meaning an increase in the medium category. Several different classes in the two classes caused different N-gain results in the experimental and control classes during the learning process. In learning activities in the experimental class, students who the STEM-PjBL Model teaches can further explore the material and find the concepts. In contrast, in the control class,

students only receive information from educators, and learning tends to be monotonous. It causes students not to interpret the material being studied.

Furthermore, it can be seen the results of the N-gain from every aspect of possessing high-level thinking skills in Figure 4 below.

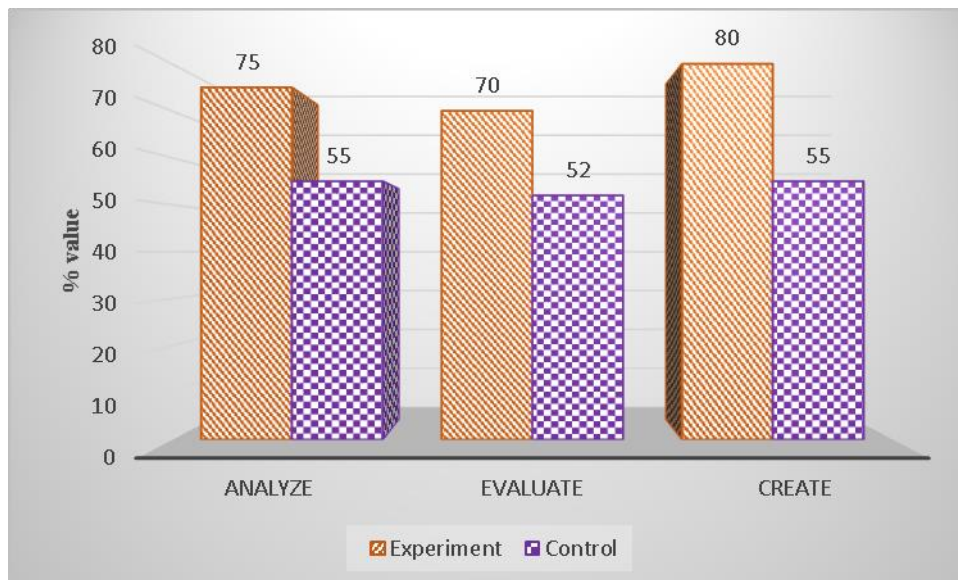


Figure 4. Graph of comparison of average N-gain values in each aspect of higher-order thinking skills

Based on Figure 4, the results on every aspect of higher-order thinking skills are more significant using STEM-PjBL Model than Direct Learning. So, it can be said that there is an influence of STEM-PjBL Model on students' ability to solve HOTS categorized questions. It can be seen that the analysis phase is 20% higher by using STEM-PjBL Model rather than Direct Learning. Students can already analyze a problem and show the relationship concept into everyday life at this stage. Through the STEM-PjBL Model, students have gone through a series of structured STEM-PjBL Model stages to distinguish, organize, and attribute the material learned.

Furthermore, students with STEM-PjBL Model scores were 18% higher at the evaluation stage than students with Direct Learning. Students can describe the information at the evaluation stage. Students write down what is known and ask according to what is meant by the problem. Students can also write down formulas and be precise in performing calculations.

Based on the results of data analysis, it can be seen in Figure 4 that the ability of students to solve the analytical category questions was 5% lower than the ability of students to solve the analytical category problems. It is because not all students can assess the solutions given based on suitable criteria. However, even though the results are lower than the analysis stage, students can plan and implement problem-solving plans appropriately, understand the purpose of the

questions correctly, and provide the right reasons. The written answers will answer the item asked in the test. The evaluation stage can be seen that get an N-gain of 70% or 0.70, which means that it belongs to the high category.

Then, in the create phase, students taught using STEM-PjBL Model get an N-gain of 25% higher than students taught through Direct Learning. The data shows that the student's ability to create is higher than the capacity of analysis and evaluation. It was happened because at this stage, students can answer correctly. Students could determine the purpose of the experiment and the steps of their work and have arranged a good and systematic investigation. It shows that the STEM-PjBL Model can give students the freedom to find their knowledge. Students gain previously unknown experience without notice but discovered by students because they can better understand the material in depth by finding themselves. It can affect the results of students' higher-order thinking skills.

By looking at the data above, the application of the STEM-PjBL Model can improve students' ability to solve HOTS categorized problems. Students discover their learning concepts to understand and analyze every given problem, including solving issues organized by HOTS. Following the opinion of the STEM-PjBL Model is a learning process that requires students to find a concept that has not been known before by conducting observation and research of the teacher's problems (Aberilla et al., 2021). It is intended that students act as subjects of learning and be involved actively in classroom learning. This is in line with the opinion that HOTS is a conception that is developed when individuals with their abilities can conceptualize things comprehensively (Hastuti et al., 2020). In line with the research results above, students can find their concepts with the STEM-PjBL Model. When students find HOTS questions based on real situations in everyday life, they can already apply learning concepts such as analyzing, evaluating and creating knowledge in class to solve problems.

In this research activity, the STEM-PjBL Model uses a concept that has not been known before, namely by observing the problems to be the subject of learning and being actively involved in classroom learning. It is in line with the opinion (Farwati et al., 2021) that finding STEM-PjBL Model can help students develop their interest and motivation to learn. Other studies indicate that students are encouraged to find their information based on the teacher's stimuli or information by using the STEM-PjBL Model. Students can learn independently and become more active in learning. In line with that, students do not always receive explanations from the teacher when the learning process occurs because they have applied the STEM-PjBL Model. Through the STEM-PjBL Model, students can also identify their problems in the

learning process. Students can also find a solution to the problem by collecting as much information as possible (Ventura et al., 2009).

Based on the data in Figure 3 and Figure 4, during the STEM-PjBL Model, students have different abilities in learning approaches or completing tasks. While working on a project, each student carries out activities, such as visualizing project activities and looking for tasks to be done, managing schedules, organizing learning materials, organizing documents, sending messages to teachers or experts, self-assessment. The description of activity description above can provide meaningful learning steps.

When students work in groups, students must work together. Cooperation takes place in basic activities, such as brainstorming, discussions, and editing documents together. Synchronize material via video or text. Organize group documents task scheduling. Some of these activities can be done as a group. STEM-PjBL Model enables the sharing of information and knowledge with other groups. For example, through presentations, peer reviews, contributing in discussion forums.

Learning with the STEM-PjBL Model can improve students' ability to solve HOTS categorized problems. This STEM-PjBL Model can improve students' thinking skills needed to solve problems. It is in line with the STEM-PjBL Model to improve students' thinking skills (Onsee & Nuangchalerm, 2019). Students receive training to observe, ask, try, reason, and communicate through syntax as in the stimulation stage. Furthermore, students have to attend and ask questions on problem formulations. Students have to request to ask questions and collect information. Students try and watch at the data collection stage to reason and ask questions at the data processing stage. By improving students' thinking skills, students can quickly answer questions in the HOTS category. HOTS questions are used to measure higher-order thinking skills, namely the ability to think that is not merely remembering, restating, or referring without processing. HOTS questions assess the capacity to transfer knowledge from one concept to another, to process and apply information, to seek for relationships between different types of data, to utilize data to solve issues, and to critically evaluate ideas and data.

Another reason for applying the STEM-PjBL Model is it can improve students' ability to solve HOTS categorized problems, because there is a systematic syntax in the STEM-PjBL Model. It was stated by (Yang, 2018) that the syntax of the STEM-PjBL Model could allow students to identify and analyze the problems they face that are useful in building students so that they are accustomed to finding a problem. In addition to the problem statement syntax, data processing syntax also supports improving students' ability to solve HOTS categorized questions. According to the research, data processing is the activity of analyzing and

interpreting data and information received by students through interviews and observations. All data collected by reading, interviewing, observing, and other means is processed, randomized, categorized, tabulated, and, if necessary, computed in a certain method, and interpreted with a given level of confidence. Data processing is also known as coding/categorization, and it is used to construct concepts and generalize information. Students find concepts that can train students' thinking skills, especially thinking at a high level. When students have a HOTS categorized problem, they can already solve it because they have to equip with the concepts they have discovered.

Based on the results above, several things explain that: (a) HOTS have developed through classroom discussion activities that hone students in giving questions, opinions, arguments, and demonstrating critical thinking skills; (b) problem solving can effectively develop higher-order thinking students; (c) aspects of HOTS consist of analyzing, comparing, inferring, and evaluating; (d) HOTS has a significant relationship in student physics performance.

Furthermore, HOTS has improved by directing students to develop science concepts in STEM-PjBL Model because STEM-PjBL Model guides students to get accustomed to finding concepts and principles. In finding, students make observations, understand, classify, make guesses, and so on without educators' help. Because educators are only as guides or facilitators by providing students opportunities to learn actively and develop optimally according to their abilities. According to the research of (Lin, 2018), the main characteristics of learning are: (1). Explore and solve problems to create, combine, and generalize knowledge; (2). Student-centered; (3). Activities to combine new knowledge and existing knowledge. Based on the opinion above, it has to conclude that STEM-PjBL Model characteristics are STEM-PjBL Model processes centered on students. Students must solve problems and connect with the knowledge that is already known and only known by students—educators only direct students to be active in learning and develop talents and skills in learning.

CONCLUSION

Based on the data on the results and discussion above, it has been concluded that STEM-PjBL Model can improve HOTS, and the results are higher than Direct Learning. However, the implementation of the STEM-PjBL Model also has obstacles. One of the barriers experienced by researchers is that students are not yet familiar with the learning model's syntax, especially in identifying problems, so the next researcher has suggested being able to understand the learning process first to be more effective. Also, students often feel confused about formulating problems from the stimulation provided. That researcher must provide more outstanding inspiration to students to immediately prepare for motivation issues—another obstacle

experienced by researchers in managing time. Students feel the time to discuss this case is still lacking data collection, so it is not uncommon for the syntax of data collection to exceed the time set to disrupt time allocation for the next syntax. So, to overcome these problems, researchers must often ask questions that students do not understand. In addition, researchers must remind the duration of the discussion to collect data from students.

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