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Integration of Multiple Intelligences Theory in Project-Based Learning, How It Impacts on Students' Critical Thinking and Mathematical Communication Skills?

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Abstract

In this study, we aim to assess the effectiveness of Project-Based Learning (PjBL) based on Multiple Intelligences (MI) theory on students' critical thinking and mathematical communication skills. This research is a quasi-experiment using non-equivalent (pre-test and post-test) control-group design. The population in this study were VIII grade students in a public junior high school in Yogyakarta and two sample classes were selected based on recommendations from teachers and had mathematical abilities that could be considered equal. The experimental class applied PjBL based on MI theory and the control class applied PjBL learning. Data collection was conducted using a test instrument in the form of description questions. This instrument is valid and reliable. Learning is said to be effective if: (1) the mean test score of critical thinking and communication skills is at least 70 (from a score range of 0-100); (2) the mean of post-test of critical thinking and communication skills is higher than the mean of pre-test; (3) the mean final score of students' critical thinking and mathematical communication skills in the experimental class is higher than the control class. Data analysis used one-sample t-test, paired-sample t-test, and T2 Hotteling test. The results of the study using the significance level $\alpha = 5\%$ showed that (1) Project-Based Learning (PjBL) learning based on Multiple Intelligence (MI) theory is effective in terms of students' critical thinking and mathematical communication skills; (2) PjBL based on MI theory learning is more effective than PjBL learning in terms of communication, but not more effective in terms of critical thinking skills. Although the data from the sample showed the acquisition of mean scores and the increase in the mean value of critical thinking learning in PjBL based on MI theory was better than PjBL learning in terms of critical thinking skill, but statistically both did not show a significant difference.

Keywords: *Critical Thinking; Mathematical Communication; Multiple Intelligences; Project-Based Learning (PjBL)*

Introduction

Efforts to improve the quality of human resource competencies are one of the things that are very important to do in order to successfully tread the life of society in the era of society 5.0. Research by González-Salamanca et al. (2020) revealed that a meaningful learning process that can motivate students to actively participate is the key to success in improving student competence. Student success in learning

is inseparable from how teachers can understand the characteristics and differences of each student. This is a very important first step to optimize the learning process. In fact, in the field, there are differences in each student's characteristics where each student has a different dominant intelligence. Therefore, teachers should be able to pay attention to and accommodate any differences in intelligence tendencies possessed by students so that teachers can then facilitate them with innovative learning strategies. Naz (2017) states that part of facilitating students' learning success lies in recognizing them based on their ability characteristics.

Learning that accommodates the differences in students' intelligence tendencies is learning based on Multiple Intelligences (MI). Learning based on MI offers teachers the opportunity to consider incorporating elements of creativity in instructional design, with the aim of facilitating student-centered activities based on the eight types of multiple intelligences mentioned by Howard Gardner (2011, 2013), allowing students to develop and improve various intellectual skills (Yavich & Rotnitsky, 2020). In the MI model, it is mentioned that each individual has their own intelligence profile consisting of eight intelligences: visual/spatial, verbal/linguistic, musical/rhythmic, logical/mathematical, bodily/kinesthetic, interpersonal, intrapersonal and naturalistic. Based on Gardner's research, each child has a dominant intelligence that is stronger and weaker in other intelligences. Therefore, it is very important in learning, teachers apply strategies that provide opportunities for students to utilize their dominant intelligence and strengthen weaknesses in other intelligences.

Using MI theory-based learning is claimed to optimize primary intelligence and standardize other intelligences, provide opportunities for authentic learning based on students' needs, interests, and talents, learning acts like the “real” world, and engages students to be active. In addition, it also allows students to explore important concepts using various domains, and search for information based on their own abilities, so it can be an important learning experience. However, in reality in the field there are still very few teachers who pay attention to students' intelligence tendencies in the learning process. MI theory-based learning has not been widely implemented in schools and multiple intelligences in learning have not been widely developed and empowered by teachers. (A. R. Setiawan, 2019; R. Setiawan et al., 2020; Setiawati, 2019; Sudarma et al., 2022).

One learning that can be integrated with MI theory is project-based learning (PjBL) (Lee et al., 2017). The design principles of PjBL emphasize the importance of projects as the primary means of teaching and students as active participants in knowledge construction. According to Delve Institute (2023), PjBL is a dynamic approach to teaching where students explore real-world problems and challenges by working in small collaborative groups that simultaneously support success and develop 21st century skills. PjBL based on MI theory is also in line with the “Merdeka” curriculum which is in the process of being implemented nationally. According to the Ministry of Education and Culture (2021), the best potential of teachers and students can be explored more deeply because in the “Merdeka” curriculum, teachers are independently given the freedom and flexibility to bring up innovations that have the potential to improve learning based on student ability preferences, according to the achievements and stages of student development, and can be contextually adjusted. Learning is carried out holistically, contextually, student-centered, and explorative.

Critical thinking and communication are two of the four important skills that students must master in the 21st century in addition to collaboration skills and creative skills according to P21st Century Learning (2019). Critical thinking and communication skills are included in learning and innovation skills. In today's digital era, which is faced with a lot of unverified and irrelevant information that can be consumed quickly, it is a challenge for us to be able to sort, filter, analyze, and evaluate the information. This is the importance of having good critical thinking skills. Critical thinking skills can help us understand and utilize information and make decisions more effectively. Critical thinking skills can be taught and learned. Activities in mathematics learning can be a means of developing critical thinking skills. Math learning activities that involve students actively gathering information, exploring, interpreting, analyzing, and evaluating as well as drawing conclusions can be an effort. These activities

also require attributes such as persistent, systematic, curious, honest, open-minded, fair and flexible. In the context of mathematics learning, in addition to the ability to solve mathematical problems logically and reflect on the role of mathematics in life, critical thinking can be a process tool for students to understand and apply reasoning processes, create and assess mathematical arguments, and validate their own thinking and answers.

The importance of mastering critical thinking skills for students is not in line with the statistical results of the level of critical thinking skills of Indonesian students. Several recent studies have shown that students' mathematical critical thinking skills are indicated to be low (Agus & Purnama, 2022; Danaryanti & Lestari, 2018; Fitria et al., 2023; Gustianingrum et al., 2023; Hidayat et al., 2019; Ifadah, 2021; Rohmah et al., 2023; Rosliani & Munandar, 2022; V. A. Sari & Adirakasiwi, 2021). So based on these studies, it is very important for teachers to try to facilitate the development of critical thinking skills in learning, more specifically in mathematics learning.

In addition to critical thinking skills, communication skills are also very important for students to master in order to face the current and future digital era as a top job skill. Having good communication skills can enable us to convey messages and express ideas clearly and effectively. Mathematical communication can equip students to obtain, process, and utilize information that is useful for solving problems. In addition to solving mathematical problems, students must also be able to communicate their ideas, both in writing and orally in order to share ideas and clarify their mathematical understanding. Therefore, it is important for students to be able to develop their mathematical communication skills. Mathematics learning activities in the classroom are strategic ways that can provide opportunities for students to be able to communicate their mathematical ideas. Efforts that can be made can be done by familiarizing students to share ideas, express opinions related to the topics studied, and ask questions, and discuss with each other, both with the teacher, and with their friends. This is in line with the NCTM (2003) statement that indicators of student communication skills in learning Mathematics are: (1) communicate their mathematical thinking coherently (logically arranged) and clearly to their peers, teachers and others; (2) use mathematical language to express mathematical ideas correctly; (3) organize and consolidate their mathematical thinking through communication; (4) analyze and evaluate mathematical thinking and strategies used by others. The importance of mathematical communication skills is not in line with the reality of the field found. Widjajanti's research (2017) concluded that students' mathematical communication skills are a serious problem that needs to be addressed. Indications of low mathematical communication skills are shown in the results of research in the field (Aminah et al., 2018; Andini & Marlina, 2021; Evriani et al., 2022; Faizah & Sugandi, 2022; Hendriana & Kadarisma, 2019; Ihdayani et al., 2021; Nurhasanah et al., 2019; Pahmi et al., 2022; Rohid et al., 2019; Wijayanto et al., 2018; Zaditania & Ruli, 2022). Based on the findings of these studies which indicate the low level of mathematical communication skills, it shows that there is a need for efforts in order to develop students' mathematical communication skills in school learning. So, there is still room for effort in developing students' mathematical communication skills.

Based on the background that has been described, it is very necessary to conduct research to add empirical evidence regarding the effectiveness of Project-Based Learning (PjBL) based on Multiple Intelligences theory in terms of students' critical thinking and mathematical communication skills. This study formulates the hypothesis that Project-Based Learning (PjBL) based on Multiple Intelligences theory is effective in terms of both variables and Project-Based Learning (PjBL) based on Multiple Intelligences theory is more effective than PjBL learning without MI in terms of both variables. This research will answer the following questions.

1. *How is the effectiveness of PjBL based on MI theory in terms of students' critical thinking and mathematical communication skills?*
2. *How is PjBL learning based on MI theory in developing students' critical thinking and mathematical communication skills?*

Methods

This research is a quasi-experiment using non-equivalent (pre-test and post-test) control-group design. The population in this study were VIII grade students in a public junior high school in Yogyakarta City. The sample consisted of two classes selected based on teacher recommendation. Both classes have mathematical abilities that can be considered equal. The experimental class applied PjBL learning based on MI theory and the control class applied PjBL learning. The learning material applied is students studying statistics material on the sub-material of the central tendency and measures of dispersion of data. Data collection is carried out with test instruments in the form of description questions that have met the validity and reliability tests (Cronbach's Alpha coefficient on critical thinking of 0.863 and communication of 0.806). Learning is said to be effective if: (1) the mean score of critical thinking and communication skills are at least 70; (2) the mean post-test score of critical thinking and communication skills is higher than the mean pre-test score; (3) the mean final score of students' critical thinking and mathematical communication skills in the experimental class is higher than the control class. Data analysis used one-sample t-test, paired-sample t-test, and T^2 Hotelling test.

Learning in the intervention class used PjBL learning based on MI theory is carried out with the following learning steps: (1) determining the members of the project heterogeneous group based on intelligence tendencies, (2) determining the type of project with heterogeneous groups based on intelligence tendencies, (3) designing the steps to complete the project with heterogeneous groups based on intelligence tendencies, (4) preparing a schedule for implementing activities to complete the project with heterogeneous groups based on intelligence tendencies, (5) completing group projects based on the Multiple intelligences learning implementation plan and monitoring by the teacher, (6) preparing reports and presentations of project product publications by empowering students' intelligence tendencies, and (7) evaluation and feedback on the process and results of projects that have been implemented. In MI-based PjBL learning, MI management is utilized in designing learning which includes determining the learning plan, determining illustrations, contexts, or selecting cases determining heterogeneous groups, and determining individual and / or group project tasks. While in the MI class, the learning steps are in accordance with the PjBL learning from Hosnan (2014). The differences between the two classes are illustrated in **table 1** below.

Table 1. Diefferences of PjBL based on MI theory an PjBL

	PjBL-MI	**PjBL**
Pre-intervention	Survey and data collection of students' dominant intelligence types	No survey and data collection of students' dominant intelligence types was conducted
Group distribution system	Each group consists of a variety of students with different types of dominant intelligence	Groups do not pay attention to students' dominant intelligence type
Accommodation of different types of student intelligence	Each student is accommodated in learning activities based on the proportion of dominant intelligences in the class	Learning activities do not pay attention to the dominant type of intelligence of students in the class
Student's projects	Students are given the freedom to determine the theme of the project to be made	The theme of the project is determined by the teacher. Students only look for their own data.

Indicators to measure critical thinking and mathematical communication skills in this study are presented in **Table 2** and **Table 3** below.

Table 2. Indicators to measure critical thinking skill

No	Indicators of critical thinking skill	Question Number
1	Understand the problem by re-clarifying the information in the problem and write down the solution steps appropriately	**1a, 2a**
2	Create mathematical models with explanations or modify (improve, process or change) existing information so that it becomes more informative.	**1b, 2d**
3	Finds or proves an error then corrects it in the given statement or problem appropriately	**1c, 2b**
4	Make the right decision for the solution of the given problem	**1d, 2c**

Table 3. Indicators to measure mathematical communication skill

No	Indicators of mathematical communication skill	Question Number
1	Express in writing mathematical situations/ideas/data/information/daily events into appropriate tables/graphics/diagrams/pictures correctly.	**1a 2a**
2	Using correct terms/notation/symbols/formulas and solving problems with the correct calculation process	**1b 2b**
3	Provide rational reasons for each step of the solution/answer of the given problem	**1c 2c**

Result and Discussion

Result

1. How Is the Effectiveness of PjBL Based on MI Theory in Terms of Students' Critical Thinking and Mathematical Communication skills?

To determine the effectiveness of Project-based Learning based on Gardner's Multiple Intelligences (MI) theory and Project-based Learning in terms of students' critical thinking and mathematical communication skills, the data collected came from the pre-test and post-test data of students' critical thinking and mathematical communication skills. The following **table 4** presents a description of the test results of students' critical thinking and mathematical communication skills.

Table 4. Descriptive results on student tests

Description	PjBl based MI Theory (n=33)				PjBL (n=31)			
	CT		MC		CT		MC	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Mean	41,2	77,5	38,9	80,7	40,3	73,2	41,1	74,4
Std. Deviation	10,5	9,3	10,2	9,4	10,2	10,3	7,6	12,1
Max Score	100	100	100	100	100	100	100	100
Min Score	0	0	0	0	0	0	0	0
Highest score	62,5	90	60,7	96,4	62,5	95	57,14	96,4
Lowest score	25	52,5	17,8	57,14	25	52,5	28,5	50

***Note*: CT**= Critical Thinking; **MC**= Math Communication

Based on the pretest results in both classes as shown in table 4 above, the mean of pretest scores of critical thinking and mathematical communication skills in the samples of both classes are relatively almost the same, but whether it can be concluded that in the population whether the results are also the same, then the next is tested first. The test was conducted with the T^2 Hotelling multivariate test on the pre-test data of critical thinking and mathematical communication skills of the two classes. This test has fulfilled the prerequisite tests of normality and homogeneity. The results of the T^2 Hotelling test are shown in the following table.

Table 5. Mean difference test results before intervention

Test	Value	F	Sign.	Result
Hotelling Trace (T^2)	0,046	0,917	0,438	H_0 accepted

Based on the Multivariate test results in **table 5** above, the significance value obtained is $0.438 > 0.05$. Then H_0 is accepted. Thus, it can be concluded that there is no difference in the mean of critical thinking and mathematical communication skills of students in the class that will get PjBL learning based on MI theory with the class that will get PjBL learning. Furthermore, hypothesis testing uses mean of post-test data.

1.1 Effectiveness of PjBL based on MI theory and PjBL in terms of critical thinking skills

The hypothesis on the first criterion for effectiveness is reviewed from the critical thinking skills

H_0 : $\mu_{bpk} \leq 69{,}99$ (PjBL based on MI teory is not effective in terms of critical thinking skills)

H_1 : $\mu_{bpk} > 69{,}99$ (PjBL based on MI teory is effective in terms of critical thinking skills)

The results of the one-sample T-test on critical thinking skills of both classes are shown in the following table.

Table 6. One-sample T-test results of critical thinking skills in both classes

Class	T	Df	Sign. (2-tailed)	Result
PjBL-MI	4,669	32	0,000	H_0 rejected
PjBL	1,710	30	0,098	H_0 rejected

Based on the results in **Table 6** above, it can be identified that the value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05$ $\left(\frac{0.000}{2} < 0.05\right)$. Thus, it can be concluded that PjBL based on MI theory is effective in terms of critical thinking skills. Likewise, with PjBL learning alone which obtained a value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05$ $\left(\frac{0.098}{2} < 0.05\right)$ which means that PjBL is also effective in terms of critical thinking skills.

Hypothesis on the second criterion for effectiveness of critical thinking skills

H_0 : $\mu_{K2} \leq \mu_{K1}$ (PjBL based on MI theory is not effective in terms of the mean value of the critical thinking skills post-test which is less than equal to the mean value of the critical thinking skills pre-test)

H_1 : $\mu_{K2} > \mu_{K1}$ (PjBL based on MI theory is effective in terms of the mean value of the critical thinking skills post-test which is less than equal to the mean value of the critical thinking skills pre-test)

The results of *the Paired-sample T-test* on the critical thinking skills of both classes are shown in the following table.

Table 7. Results of the Paired-sample T-test of critical thinking skills in both classes

Class	T	Df	Sign. (2-tailed)	Result
PjBL-MI	17,347	32	0,000	H_0 rejected
PjBL	17,879	30	0,000	H_0 rejected

Based on the results in **Table 7** above, it can be identified that the value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ (0.000 < 0.05)$. Thus, it can be concluded that PjBL based on MI theory is effective in terms of the mean value of the critical thinking skills post-test which is more than the mean value of the critical thinking skills pre-test. Likewise, with PjBL learning alone which obtained a value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ \left(\frac{0.000}{2} < 0.05\right)$ which means that PjBL is also effective in terms of critical thinking skills based on the mean of post-test value which is higher than the mean of pre-test value.

1.2 Effectiveness of PjBL Based on MI Theory and PjBL in Terms of students' Mathematical Communication Skills

Hypothesis on the first criterion for effectiveness in terms of communication skills

H_0 : $\mu_{km} \leq 69,99$ (PjBL based on MI teory is not effective in terms of math communication skills)

H_1 : $\mu_{km} > 69,99$ (PjBL based on MI teory is effective in terms of math communication skills)

The results of the *one-sample T-test* on the math communication skills of both classes are shown in the following table.

Table 8. Results of the One-sample T-test of math communication skills in both classes

Class	T	Df	Sign. (2-tailed)	Result
PjBL-MI	6,559	32	0,000	H_0 rejected
PjBL	2,031	30	0,051	H_0 rejected

Based on the results in **Table 8** above, it can be identified that the value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ (0.000 < 0.05)$. Thus, it can be concluded that PjBL based on MI theory is effective in terms of communication skills. Likewise, in PjBL learning only which obtained the value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ \left(\frac{0.051}{2} < 0.05\right)$ which means that PjBL is also effective in terms of mathematical communication skills.

Hypothesis on the second criterion for effectiveness of communication skills.

H_0 : $\mu_{E2} \leq \mu_{E1}$ (PjBL based on MI theory is not effective in terms of the mean value of the communication skills post-test which is less than equal to the mean value of the communication skills pre-test)

H_1 : $\mu_{E2} > \mu_{E1}$ (PjBL based on MI theory is effective in terms of the mean value of the communication skills post-test which is less than equal to the mean value of the communication skills pre-test)

The results of *the Paired-sample T-test* on the math communication skills of both classes are shown in the following table.

Table 9. Results of the Paired-sample T-test of communication skills in both classes

Class	T	Df	Sign. (2-tailed)	Result
PjBL-MI	28,256	32	0,000	H_0 rejected
PjBL	18,098	30	0,000	H_0 rejected

Based on the results in **Table 9** above, it can be identified that the value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ (0.000 < 0.05)$. Thus, it can be concluded that PjBL based on MI theory is effective in terms of the mean value of the post-test of communication skills which is more than the mean value of the pre-test of communication skills. Likewise, with PjBL learning alone which obtained a value of $t > 0$ and $\frac{sig.(2\ tailed)}{2} < 0.05\ (0.000 < 0.05)$ which means that PjBL is also effective in terms of mathematical communication skills based on the mean of post-test value which is higher than the mean of pre-test value.

1.3 Comparing the Effectiveness of Project-Based Learning Based on Multiple Intelligences (MI) Theory with Project-Based Learning without MI

Testing for the comparison of effectiveness in both classes after learning is done on the results of the post-test of critical thinking and mathematical communication skills in both classes. The results of the normality and homogeneity assumptions of the post-test data in this study have been met so that the data can be continued for the Hotelling Trace (T^2 Hotelling) test MANOVA analysis. The following is a table of Hotelling Trace test output results on data after learning from both classes.

Table 10. Results of the mean difference test after intervention

Test	Value	F	Sign.	Result
Hotelling Trace (T^2)	0,140	2,792	0,048	H_0 rejected

Based on the Multivariate test results in **Table 10** above, the significance value obtained is $0.048 < 0.05$. Then H_0 is rejected. Thus, it can be concluded that there is a mean difference in critical thinking and mathematical communication skills after learning in classes that get PjBL based on MI theory with classes that get only PjBL learning. Furthermore, the Independent Sample T-test was conducted to find out which variables contributed to the difference and which one was higher. The results of the Independent Sample T-test test to determine whether there is a difference in the mean value of critical thinking skills of the two classes are shown in the following table.

Table 11. Independent results on the mean value of critical thinking skills of the two classes

Independent Sample T-test	T	Sign. (2-tailed)	Result
Equal variances assumed	1,789	0,079	H_0 accepted

Based on the results in **Table 4** Group Statistics, the mean critical thinking skill after learning in the class that received PjBL based on MI theory learning was higher than the class that received PjBL learning. However, based on **Table 11** Independent Sample T-test, the value of

$Sig.(2-tailed) = 0.79 > 0.05$ and $t_{count} = 1.789 < t_{table} = 1.998$. Therefore, H_0 is accepted. Thus, it can be concluded that there is no significant difference in the mean critical thinking skill after learning in the class that received PjBL based on MI theory learning with the class that received only PjBL learning.

Furthermore, the results of the Independent Sample T-test to determine whether there is a difference in the mean value of communication skills of the two classes are shown in the following table.

Table 12. Independent results on the mean value of communication skills of the two classes

Independent Sample T-test	T	Sign. (2-tailed)	Result
Equal variances assumed	2,334	0,023	H_0 rejected

Based on the results in Table 12 Independent Sample T-test, the value of $Sig.(2-tailed) = 0.23 < 0.05$ and $t_{count} = 2.334 > t_{table} = 1.998$. Therefore, H_0 is rejected. Thus, it can be concluded that there is a mean difference in communication skills after learning in classes that get PjBL based on MI theory learning with classes that get PjBL learning. Then based on the results in **Table 4** Group Statistics, it is obtained that the mean communication skill in the PjBL-MI class is higher than the mean in the PjBL class, it can be concluded that the mean communication skill after learning in the class that received PjBL based on MI theory learning is significantly higher than the class that received PjBL learning.

Discussion

Helping students learn effectively is a challenge for teachers. Therefore, teachers should continuously review and examine various flexible learning approaches to facilitate students' learning needs. The traditional view of teaching and learning mathematics as a straightforward, technical process focused on specific teaching objectives and learning outcomes is evolving (Li & Schoenfeld, 2019; Sulaiman et al., 2010). The process of learning mathematics is related to doing mathematics and processes such as investigating, reflecting, reasoning, providing arguments, finding relationships, communicating, and others, so that the results are expected that students can have the ability to deal with real-world problems that they will face in the future (Kolar-Begović et al., 2017; Kunwar et al., 2022).

Students are not seen as a single individual with a single ability, but students are individuals who have a variety of abilities and intelligences that must be developed. Teachers are encouraged to adopt progressive teaching styles to accommodate students' diverse abilities, thus enabling students to excel in their learning. Alternative teaching strategies should be oriented towards meeting the needs of these diverse students by establishing a conducive learning environment for students. One of the learning alternatives that teachers can do is to combine a learning approach with learning strategies based on certain theories. Theoretically, a learning approach combined with learning strategies based on certain theories will be more effective if applied in classroom learning. However, to prove its effectiveness, empirical research is needed in the field.

This learning research applies learning with PjBL approach based on MI Gardner's theory as an intervention class. Learning with PjBL based on MI Gardner's theory is not learning that aims to improve every intelligence possessed by students, but the multiple intelligences are empowered and accommodated so that students can enjoy learning and interpret every process they go through in learning according to the type of intelligence they have. Theoretically, learning with PjBL based on Gardner's MI theory can make students more active and can follow learning well because this learning optimizes primary intelligence and standardizes other intelligences, provides opportunities for authentic learning

based on students' needs, interests, and talents, learning acts like the “real” world, involving active students (Lunenburg & Lunenburg, 2014) which allows students to explore important concepts using various domains, and search for information based on their own abilities, so that it can be an important learning experience for students. The basic idea in MI-based learning is to design learning activities and teaching materials according to the proportion of students' intelligence types in the class. The learning design includes determining lesson plans, determining illustrations, selecting cases, determining heterogeneous groups, and determining individual and group assignments in learning. The hope is that by trying to accommodate the various types of intelligence of students in the class according to their proportions, it can make learning more meaningful for students.

In the implementation of learning, applying PjBL learning steps, namely through determining group projects, planning the steps for completing projects, determining schedules and materials / tools, completing projects, preparing final reports, and evaluating projects which are activities that make students actively collaborate in learning. After that, with the combination of MI theory in learning activities, it can make learning more meaningful and make students more able to enjoy their learning process. In a series of project completion processes, the researcher observed that more than 75% of students looked very enthusiastic about working together, collaborating, and cooperating with each other to share roles in completing the project.

The results of the analysis in this study resulted in a description of the effectiveness of PjBL learning based on Gardner's MI theory in terms of students' critical thinking and mathematical communication skills. These results can make the basis for other researchers to apply learning like this to improve students' critical thinking and mathematical communication skills. The following is a description of the findings in this study regarding the effectiveness of PjBL learning based on Gardner's MI theory in terms of students' critical thinking and mathematical communication skills.

2. PjBL Learning Based on MI Theory in Developing Students' Critical Thinking and Mathematical Communication Skills

2.1 The Critical Thinking Skill

Based on the results of descriptive analysis and inferential analysis, PjBL based on MI theory is effective in terms of critical thinking skills with a significant increase in critical thinking skills test results. The increase in the mean value of critical thinking skills in the intervention class is thought to be influenced by the strategy of using Multiple Intelligences (MI) theory as the basis for Project Based-Learning (PjBL) learning used. This is in line with the results of Kusuma & Widjajanti's (2019) research which states that Multiple Intelligences (MI) based learning is more effective than conventional scientific learning. Likewise, the results of research by Inan & Erkus (2017) and Benazira et al. (2021) which states that mathematics learning based on Multiple Intelligences (MI) is more effective than ordinary learning without using the Multiple Intelligences (MI) base in terms of mathematics academic achievement.

The increased critical thinking skills are thought to be due to the implementation of PjBL based on MI theory which is oriented towards student-centered learning, where students build knowledge by freely linking prior knowledge with new knowledge through problem solving by completing projects related to everyday life which allows students to carry out analysis, thought processes, evaluation, and creation. This agrees with Al-Khrisha (2021) who states that in project-based learning, it allows students to hone skills to distinguish right from wrong and the advantages and disadvantages of a result based on the facts and information contained in the project. In addition, PjBL learning combined with Multiple Intelligences (MI) theory allows students to optimize the various types of intelligence they have to express their abilities, strengths, and talents, and allows students to explore concepts, seek information through student-centered instructional activities in order to complete projects that are close to the real world. This is in line with Afandi's (2021) opinion which states that MI theory-based learning can optimize primary intelligence and involve active students who allow students to explore important

concepts using various domains, and seek information based on their own abilities, so that it can be an important and authentic learning experience.

Some things related to the steps of PjBL based on MI theory are thought to affect the improvement of students' critical thinking skills, among others, determining projects in the first step provides an opportunity for students to choose and determine projects, group projects with notes in accordance with the direction of the task given by the teacher. In this case, the teacher through this activity stimulates students to analyze and formulate problems that must be solved through a series of project completion. This is in line with the opinion of Kokotsaki (2016) which states that there is the first syntax of PjBL, students are trained to think at a high cognitive level in the form of analyzing problems to formulate problems.

Furthermore, in the step of designing the steps to complete the project, students are given the opportunity to design and determine the steps to complete the project along with its management. At this stage allows students to analyze collaboratively in groups related to changes in form or modifications to add functions and steps so as to produce a truly meaningful project completion design. According to Sularmi et al (2018) at this step students have done synthetic thinking. After that, in the step of preparing a project implementation schedule, students are given the opportunity to develop a schedule for carrying out their project along with the division of tasks for each group member (if a group project).

Furthermore, in the step of completing the project with teacher facilities and monitoring, students are given the opportunity to complete the project in the way and creativity of students, such as reading, investigating, researching, observing, interviewing, accessing sources on the internet. Meanwhile, the teacher acts as a facilitator and project monitor. Monitoring is done by facilitating every process that students go through. In steps two through four, it is thought to be the most influential stage in improving students' critical thinking skills. At this stage, through discussion, students explore information, connect information, analyze problems to find solutions in completing the project. This is in line with the opinion of Sari et al. (2019), through discussion, students conduct a simple SWOT analysis by examining some strengths, finding weaknesses, analyzing opportunities that have the potential to become project ideas, and predicting threats that may occur. This stage can develop students' critical thinking, analyze problems, and generate ideas/actions that can be useful and expressed in the form of projects.

Furthermore, in the last step, namely compiling reports and evaluating results, students are given the opportunity to compile reports and present the results in front of the teacher and other students. Project results can be in the form of written products, works of art, or technology. At this stage, students' communication skills can be trained. In the presentation stage, students convey the results orally, describe the steps, and answer questions from other students. After that, in the end, students evaluate the successes and failures encountered. Thus, the steps of PjBL based on MI theory can support students' critical thinking skills.

2.2 The Mathematical Communication Skill

Based on the results of descriptive analysis and inferential analysis, PjBL based on MI theory is effective in terms of mathematical communication skills with a significant increase in mathematical communication skills test results. The increase in the mean value of communication skills in the intervention class is thought to be influenced by the strategy of using Multiple Intelligences (MI) theory as the basis for Project Based-Learning (PjBL) learning used. This is in line with the results of Kusuma & Widjajanti's (2019) research which states that Multiple Intelligences (MI) based learning is more effective than conventional scientific learning. Likewise, the results of research by Inan & Erkus (2017) and Benazira et al. (2021) which states that mathematics learning based on Multiple Intelligences (MI) is more effective than ordinary learning without using the Multiple Intelligences (MI) base in terms of mathematics academic achievement.

Improved communication skills are suspected because the implementation of PjBL based on MI theory learning facilitates students engage in authentic situations such as communicating with people beyond the classroom, and they can also take advantage of other resources such as the internet, local communities to help with their projects, in addition to reflecting and communicating about their learning experiences with their peers, partners, or friends (Ferianda & Mukarto, 2017; Kohonen, 1992). In completing the project, there is face-to-face promotive interaction which means that students should provide effective guidance to their peers by discussing, exchanging sources, reasoning, and providing feedback. In addition, project-based learning that combines with multiple intelligences (MI) learning allows providing opportunities for students to build knowledge by understanding concepts variably according to their intelligence tendencies so that it is expected that learning carried out by students can be more meaningful and students feel enjoy the learning process.

In PjBL based on MI theory class, there are various types of intelligence tendencies possessed by students in the class. All types of intelligence possessed by students are used to form heterogeneous student groups. Each group, there are various kinds of students who have different dominant intelligence tendencies. This allows to provide opportunities for students to be able to collaborate, cooperate, convey ideas and ideas in each group and can complement each other in tasks to complete the project. Students are given the freedom to think, learn, understand various problems, express their reasoning power so that they can contribute to the group, because this learning is student-centered learning. As an implication, students can build knowledge by linking prior knowledge with new experiences to form new knowledge so as to gain a deeper understanding of mathematics learning. Thus, PjBL learning based on MI theory is effective for improving students' mathematical communication skills.

Some things related to the steps of PjBL based on MI theory are thought to affect the improvement of students' mathematical communication skills, among others, determining projects in the first step provides an opportunity for students to choose and determine projects, group projects with notes in accordance with the direction of the task given by the teacher. In this case, the teacher through this activity stimulates students to connect mathematical ideas and representations of situations in the real world. This is in line with the opinion of Tamba (2023) which states that project-based learning is contextual learning that is close to everyday life where students can connect mathematical ideas with real-world representations.

Furthermore, in the step of designing the steps to complete the project, students are given the opportunity to design and determine the steps to complete their project along with its management. After that, in the step of developing a project implementation schedule, students are given the opportunity to develop a schedule for carrying out their project along with the distribution of tasks for each group member.

Furthermore, in the step of completing the project with teacher facilities and monitoring, students are given the opportunity to complete the project in the way and creativity of students, such as reading, investigating, researching, observing, interviewing, accessing sources on the internet. Meanwhile, the teacher acts as a facilitator and project monitor. Monitoring is done by facilitating every process that students go through. In this second to fourth step, through discussion, students explore information, connect information, use speaking and writing skills in a mathematical context to find solutions in completing the project so that there is a transformation of mathematical information from the communicator to the communicant in the group. This is in line with the opinion of Tamba (2023), through discussion, it is an effective means for students to use speaking and writing skills in the context of mathematics.

Furthermore, in the last step, namely compiling reports and evaluating results, students are given the opportunity to compile reports and present the results in front of the teacher and other students. Project results can be in the form of written products, works of art, or technology. At this stage, students' communication skills can be trained. In the stage of presenting the results, students convey the results

orally, describe the steps, and answer questions from other students. After that, at the end, students evaluate the successes and failures encountered. In addition, in making models and diagrams, students can gain graphic skills that support their communication skills, namely expressing mathematical ideas/ideas into concrete ideas in the form of visual diagrams/graphics, notations, and mathematical symbols. This is in line with the opinion of Tamba (2023) which states that project-based learning can develop students' mathematical visualization skills. Thus, the PjBL steps based on MI theory can support students' mathematical communication skills.

Conclusion

This study which aims to determine the effectiveness of PjBL based on MI theory in terms of students' critical thinking and mathematical communication skills shows positive results. These results indicate that PjBL based on MI theory is effective in terms of students' critical thinking and mathematical communication skills. In addition, PjBL based on MI theory is more effective than PjBL learning in terms of mathematical communication, but not more effective in terms of critical thinking skill. Although the data from the sample showed that the mean score and the increase in mean score of PjBL based on MI theory were better than PjBL learning in terms of critical thinking skill, statistically both did not show a significant difference.

This result is based on descriptive analysis and inferential analysis which shows a significant increase in students' critical thinking and mathematical communication skills. This increase is thought to be due to the use of MI as the basis for PjBL learning. In addition, the PjBL steps consisting of (1) determining the members of the project heterogeneous group based on intelligence tendencies, (2) determining the type of project with heterogeneous groups based on intelligence tendencies, (3) designing the steps to complete the project with heterogeneous groups based on intelligence tendencies, (4) preparing a schedule for implementing activities to complete the project with heterogeneous groups based on intelligence tendencies, (5) completing group projects based on the Multiple intelligences (M) learning implementation plan and monitoring by the teacher, (6) preparing reports and presentations of project product publications by empowering students' intelligence tendencies, and (7) evaluation and feedback on the process and results of projects that have been carried out to provide opportunities for students to actively develop their critical thinking and mathematical communication skills. This research has limitations on the small number of respondents involved. It would be better if further research could increase the scope of respondents, so that the results of the study could have a wider impact. In addition, learning can be done by varying both the learning, and the attributes that will be seen. Integration with new MI learning is one form of accommodation of diversity owned by students. There are still many forms of diversity owned by students that can be explored in the future.

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