The students’ achievement of algebraic thinking ability using Merrill’s First Principles of Instruction

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Abstract. The purpose of this study is to develop algebraic thinking ability. It was because of the low ability of students in the mathematical representation using models, poor understanding in the use of symbols, errors in solving equations, and difficulties in composing general rules. This research used the quantitative approach using posttest-only control group design. The subjects in this study were 124 8th-grade students of junior high school in Tangerang, Indonesia. The students engaged in algebraic learning using Merrill’s First Principles of Instruction (MFPI). The results show that the MFPI affected the achievement in algebraic thinking ability when the prior mathematical knowledge was in the high and intermediate category, while it did not significantly affect the achievement when the prior mathematical knowledge was in a low category. It was because MFPI learning requires good prior knowledge to build new knowledge. MFPI learning should be an alternative one for mathematics teachers. MFPI can improve students' algebraic thinking ability. Also, MFPI can develop an atmosphere of discussion, collaboration, and motivating each other in the learning.

1. Introduction

Algebraic thinking is a person's ability to build meaning for the symbols and algebraic operations regarding arithmetic. NCTM emphasizes algebraic thinking as an essential standard in the school curriculum. Four principles in the curriculum for developing algebraic learning, namely generalization, problem-solving, modelling, and functional [1]. Based on these four principles, researchers use generalizations, problem-solving and modelling as indicators of algebraic thinking ability. To develop the algebraic thinking ability, we have to first develop students' conceptual understanding by involving students in understanding problems, modelling problems, and analyzing patterns in solving the problems.

Algebraic thinking is activities that usually involve students, namely generational activities, meta-global ranking activities, and transformation activities [2]. Generational activities are activities that produce algebra includes the formation of expressions and equations, including the formation of equations that contain an unknown quantity that represents a problem situation, generalization of expressions that arise from geometric patterns or lines of numbers, and expressions of rules governing relationships numerical. Therefore, the indicators used in this study are the ability to generalize, mathematical modelling and problem-solving.
Through problem-solving, mathematical modelling and generalization, students are likely to gain experience using the knowledge and ability that they already have to apply to non-routine problem-solving. Students can practice integrating the concepts and ability that they have learned. Students can be trained to make decisions because they have the ability on how to collect relevant information, analyze information and realize the need to re-examine the results they have obtained.

Problems in algebraic thinking ability that students face in the learning process are that they have difficulty in representing problems or word problems in the form of equations and algebraic models [3]. For example, students sometimes get confused in distinguishing the use of plus (+) and minus (−) signs, when they are used to indicate addition and subtraction operations in arithmetic, and when they are used to show positive and negative numbers in algebraic operations [4]. These difficulties affect the student’s low ability to represent problem into mathematical models and the difficulty in determining the value of unknown variables.

The characteristics of students' thinking in solving mathematical problems especially in algebra are so diverse that they become a very important issue in the world of mathematics education [5]. The ability of students to solve problems related to algebraic thinking abilities varies, one of the factors that influence is the prior mathematical knowledge possessed by students. Each student has different mathematical prior knowledge. Students’ thinking ability is related to the learning process.

Merrill’s First Principles of Instruction (MFPI) is learning that can develop students' algebraic thinking ability. The MFPI is a teaching practice that has the basic principles of (1) facilitating students in solving real problems, (2) activating the students’ existing knowledge as the baseline of a new knowledge, (3) facilitating the students to gain the new knowledge, (4) facilitating the students in applying the knowledge, and (5) facilitating the students to integrate the knowledge with the daily life context [6]. The process of gaining new knowledge requires good mathematical abilities. The purpose of this study is to determine differences in algebraic thinking abilities of students who received MFPI compared to the conventional learning based on the students’ prior mathematical knowledge.

2. Method
The experimental design which was used in this research was posttest-only control group design. We administered a test of algebraic thinking ability after the students got the MFPI treatment. The subjects in this study are 124 8th-grade students of public junior high schools in Tangerang, Indonesia. The reason for choosing the subjects is because the 8th-grade students have been able to answer questions independently. Among the subjects, we selected the experimental group consisted of 64 students, with 15 students in the high prior mathematical knowledge category, 41 students in the intermediate, and eight students in the low categories. We also selected the control group consisted of 60 students, with ten students in the high prior mathematical knowledge category, 41 students in the intermediate category, and nine students in the low category.

The instrument of algebraic thinking ability in this study has been validated by experts. The prior mathematical knowledge test was used to measure the students' prior mathematical knowledge before being treated using MFPI for the experimental group and using conventional learning for the control group. The prior mathematical knowledge test also used the basic material in algebra. We categorized the prior mathematical knowledge based on the criteria in Table 1.

| Table 1. The prior mathematical knowledge category |
|-----------------------------------------------|
| Criteria                      | Category   |
| n > 83.31                     | High       |
| 58.23 ≤ n ≤ 83.31             | Intermediate|
| n < 58.23                     | Low        |
The instrument of algebraic thinking ability in the form of post-test consisting of questions contains indicators of mathematical modelling, problem-solving, and mathematical generalization. We have tested the reliability of the algebraic thinking ability test and obtained the reliability coefficient of 0.68. This coefficient shows that the problem has high reliability. The validity of the items was also in the very good category. Finally, we used the inferential and descriptive statistics to analyze the collected data. The statistical analysis used in this research was t-test, Mann-Whitney test, and ANOVA.

3. Results and Discussion
The descriptive data on the student’s achievement in algebraic thinking ability based on their prior mathematical knowledge category was described in Table 2.

| Category     | Learning approach | Number of students | Mean   | Deviation standard | Number of students | Mean   | Deviation standard |
|--------------|-------------------|--------------------|--------|--------------------|--------------------|--------|--------------------|
| High         | MFPI              | 15                 | 75.61  | 15.99              | 41                 | 55.71  | 20                 |
|              | Conventional      | 10                 | 53.4   | 26.3               | 41                 | 44     | 19.2               |
| Intermediate | MFPI              | 41                 | 55.71  | 20                 | 8                  | 46.38  | 25.63              |
|              | Conventional      | 41                 | 44     | 19.2               | 9                  | 36.3   | 10.5               |
| Low          | MFPI              | 8                  | 46.38  | 8                  | 64                 | 44.39  | 60                 |
|              | Conventional      | 9                  | 36.3   | 9                  | 60                 | 19.84  |                    |

Table 2 shows that the average score of the students’ achievement in all prior mathematical knowledge categories using MFPI learning was higher than the average score using conventional learning. In the high prior mathematical knowledge category, the achievement data for students who obtained conventional learning is more diverse than the students who received MFPI learning as seen from the standard deviation value. On the contrary, in the intermediate and low prior mathematical knowledge category, the achievement data for students who received MFPI learning is more diverse than the students who received conventional learning.

Further, the inferential analysis could be done after testing the basic assumption of normality and homogeneity of the data. The result of the normality test is illustrated in Table 3.

| Category             | Learning | N  | SW  | Sig.  | H₀   | Interpretation |
|----------------------|----------|----|-----|-------|------|----------------|
| Prior mathematical   | MFPI     | 15 | 0.953 | 0.576 | Accepted | Normal         |
| High                 | Conventional | 10 | 0.855 | 0.660 | Accepted | Normal         |
| Intermediate         | MFPI     | 41 | 0.900 | 0.002 | Rejected | Not Normal     |
|                      | Conventional | 41 | 0.941 | 0.035 | Rejected | Not Normal     |
| Low                  | MFPI     | 8  | 0.884 | 0.208 | Accepted | Normal         |
|                      | Conventional | 9  | 0.798 | 0.019 | Rejected | Not Normal     |

From the Table 3, we could see that for the high prior mathematical knowledge, the value of Sig. is more than 0.05 which makes the null hypothesis whether the data is normally distributed, is accepted.
Thus, the parametric inferential test could be done using t-test to determine the achievement of algebraic thinking ability based on the high prior mathematical knowledge category. In the intermediate and low prior mathematical knowledge category, the Sig. value for the MFPI learning is less than 0.05, so the null hypothesis is rejected. It can be concluded that the achievement data is not normally distributed.

**Table 4. The homogeneity test of the post-test data**

| Category | Learning     | N  | F       | Sig. | $H_0$   | Interpretation         |
|----------|--------------|----|---------|------|---------|------------------------|
| MPK      | High MFPI    | 15 | 6.274   | 0.020| Rejected| Not homogeneous        |
|          | Conventional | 10 | -       | -    | -       |                        |

In Table 4, we could see that the value of Sig. on the achievement of students' algebraic thinking ability in the high prior mathematical knowledge category is less than 0.05, so the null hypothesis is rejected. In conclusion, the data of the achievement of students' algebraic thinking ability in the high MPK category are not homogeneous.

**Table 5. Mean-difference test of the post-test data**

| Category          | Learning     | N  | $t'$  | (Z)  | Sig    | $H_0$ | Interpretation         |
|-------------------|--------------|----|-------|------|--------|-------|------------------------|
| High Prior MPK    | MFPI         | 15 | 2.391 |       | 0.032  | Rejected| There is difference    |
|                   | Conventional | 10 | -     | -    | -      | -     |                        |
| Intermediate MPK  | MFPI         | 41 | -     | 2.779| 0.005  | Rejected| There is difference    |
|                   | Conventional | 41 | -     | -    | -      | -     |                        |
| Low MPK           | MFPI         | 8  | -     | 1.304| 0.192  | Accepted| There is no difference |
|                   | Conventional | 9  | -     | -    | -      | -     |                        |

Table 5 shows that the value of Sig on the achievement of students' algebraic thinking ability in the high and intermediate prior mathematical knowledge is less than 0.05, so the null hypothesis is rejected. In conclusion, data on the achievement of algebraic thinking abilities of students who received MFPI were better than students who received conventional learning regarding the high and intermediate prior mathematical knowledge category. Meanwhile, the Sig value on the achievement of students' algebraic thinking ability in the low prior mathematical knowledge category is more than 0.05, so the null hypothesis is accepted. The conclusion is there is no difference in the data on the achievement of algebraic thinking ability of students who received MFPI and students who received conventional learning regarding the low prior mathematical knowledge category. It means that learning does not affect algebraic thinking ability when prior mathematical knowledge is low.

Furthermore, we could also learn the interaction between the type of learning and the prior mathematical knowledge category towards the students' achievement in the graph illustrated in Figure 1. The graph in Figure 1 shows that there is no interaction between prior mathematical knowledge and learning towards the achievement of students' algebraic thinking ability. It means that the type of learning and prior mathematical knowledge do not have a significant influence on the achievement of students' algebraic thinking ability.
The interaction between the type of learning and prior mathematical knowledge to achievement algebraic thinking

Overall, the average achievement of algebraic thinking ability of the students who get MFPI learning is better than students who get conventional learning. Sequentially, the highest difference in the average achievement of algebraic thinking among students who received MFPI and conventional learning was the high, intermediate, and low prior mathematical knowledge.

Figure 2. Graphics the student’s achievement of algebraic thinking based on learning

Figure 2 indicated a graph of the average achievement of algebraic thinking ability based on learning. In MFPI learning, high prior mathematical knowledge students get the highest score of 88 in
the generalization indicator, while the lowest score is students who get conventional learning in the low prior mathematical knowledge category by 26. The highest average mathematical modelling indicators in the high prior mathematical knowledge category students who get MFPI learning was 72, while the lowest is in the high prior mathematical knowledge category of students who get conventional learning. The highest average problem-solving indicators were high prior mathematical knowledge students who received MFPI, while the lowest were students who received MFPI learning at low prior mathematical knowledge.

Based on the results of this study, it can be obtained some of the findings of the study, namely MFPI influences the achievement of students' algebraic thinking ability in high and intermediate prior mathematical knowledge categories, while students of low prior mathematical knowledge category do not show differences in these achievements. It developed with students in the high and the intermediate prior mathematical knowledge category. Learning mathematics requires prior mathematical knowledge as capital to build new concepts. Students who have high prior mathematical knowledge already have considerable capital to build a new concept so that it will have a positive impact on the results obtained.

One problem-based learning and activating students are Merrill's First Principles of Instruction (MFPI). MFPI is learning that focuses on problems and involves students into four phases, namely activation, demonstration, application, and integration. In the activation phase, the teacher activates students by giving several questions about the material that has been studied by students. This aims to determine the readiness of students to receive material. Also, the teacher also motivates students by explaining the benefits of learning mathematical material so that students will be more motivated in learning — the need for this activation phase to prepare students to study the material and reduce students' anxiety and fear of mathematics.

In the demonstration phase, the teacher demonstrates props that can be used by students in understanding a concept. After that, the teacher gives the teaching aids to each group so that students better understand the material conveyed by the teacher. In groups, students discuss using teaching aids and work on student worksheet to understand the material concepts explained by the teacher — various research results that show that the role of manipulative objects in mathematics learning can help children to understand abstract mathematical concepts [7].

In the application phase, the teacher gives students the problems found in the student worksheet. Students in groups discuss in solving the problem. The discussion process that took place gave a positive contribution between group members so that students were more able to apply the material to solve problems. The advantages of the discussion process include: (1) can accelerate the understanding of learning material and skills using problem-solving strategies, (2) help students construct mathematical understanding, (3) inform that mathematicians usually do not solve problems individually but build ideas with experts others in one team, and (4) help students analyze in solving problems well [8].

In the integration phase, the teacher applies problems related to students' daily lives. The purpose of the integration phase is so that students better understand the material that has been conveyed by the teacher and understand that the material is useful in the daily lives of students. Teachers are expected to prepare real-world situations and their context for students to make mathematical ideas reasonable, acceptable to students. Thus it will provide opportunities for students to recognize and appreciate the mathematical relationship with their lives [9].
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Figure 3. The students’ activities during the learning

The link between MFPI and algebraic thinking ability is based on a problem that must be solved by the students. MFPI facilitates the development of algebraic thinking ability with its four phases. In these four phases, students who have low prior mathematical knowledge do not actively participate in each phase. The teacher has facilitated by making heterogeneous groups and giving feedback to each group. Figure 3 shows one of the phases when students are discussing in solving problems on a worksheet. Habits in solving problems, make students become problem solvers who are reliable, critical and creative.

Subsequent findings based on Figure 2 show that overall the indicators of generalization, problem-solving and mathematical modelling of students who received MFPI learning was superior to conventional learning. The ability to generalize students is superior to other indicators. It is because students often make mistakes in understanding the problem, errors in symbols such as writing the given length of the edge using \( v \) (which should be for volume), errors in substituting the value of a variable, and errors in calculating. Research argues that focusing on relationships and not just counting numbers, focusing on representation in problem-solving, and focusing on the meaning of the same signs are important in algebraic learning [2]. Most students, if given a mathematics problem, they immediately calculate without understanding the meaning of the question [10] and the relationship of each sentence so that students have difficulty in solving the problems and represent the problem.

4. Conclusion

Students who were given MFPI learning gained achievement of algebraic thinking ability better than students who were given conventional learning based on high and intermediate prior mathematical knowledge. Students who obtain MFPI learning achieve good results on all indicators that are measured compared to students who get conventional learning. The indicator of the most optimal algebraic thinking ability was on the generalization indicator.

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