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The Effect of Algebra Tiles Among Form Four Students on The Achievement of Conceptual Knowledge, Procedural Knowledge and Mental Effort for The Topic of Quadratic Equations

Nur Yusra Rahizan[1], Rohaidah Masri[1*], Zamzana Zamzamir[1], Fainida Rahmat[1] and Hazura Mohamed[2]

[1] Department of Mathematics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[2] Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia

[*]Corresponding author: rohaidah@fsmt.upsi.edu.my

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Abstract

The main aim of this study was to investigate the effect Algebra Tiles as manipulative tool on Form Four students' overall achievement, conceptual knowledge, procedural knowledge and mental effort in learning the topic of Quadratic Equations. A quasi-experimental pre-post control design of a pre–post control group was conducted with Form Four students from a national secondary school in Shah Alam, Malaysia. Four classes were randomly assigned to either two classes the treatment group (n=60) and two classes the control group (n=60). The treatment group used the Algebra Tiles as teaching tool (PJA), while the control group underwent conventional teaching method (PK) for the topic of Quadratic Equations. There are two instruments used in this study: the Quadratic Equation Achievement Test (UPPK) and the Mental Effort Rating Scale (SPUM). Data was analyzed using descriptive analysis (mean and standard deviation) and inferential statistics through MANOVA. The findings of the study showed that there were significant differences between the conventional teaching method (PK) group and the treatment group used the Algebra Tiles as teaching tool (PJA) in students' overall achievement, conceptual knowledge achievement, procedural knowledge achievement and mental effort [$F(4,115) = 3576.75$, $p < 0.05$]. The mean for the overall achievement (76.87), achievement of conceptual knowledge (20.75) and achievement of procedural knowledge (17.67) for the PJA group was higher than the mean for the PK group. Meanwhile, the mean for mental effort for the PJA group (4.92) was lower than the PK group. The findings indicated significant difference between the PK and PJA groups in terms of overall achievement, conceptual knowledge, procedural knowledge and mental effort. The PJA group outperformed the PK group in terms of overall achievement, conceptual knowledge and procedural knowledge, while the mean for mental effort for the PJA group was lower than the PK group. As conclusion, the use of Algebra Tiles can enhance students' conceptual and procedural knowledge significantly in learning Quadratic Equations while reducing students' cognitive load. The students exhibited a favorable perception of algebra tiles as tangible tools for mastering algebraic concepts especially in solving Quadratic Equations. Therefore, the

findings of this study recommend that Algebra Tiles can be an effective tool in promoting deeper understanding of abstract mathematical concepts, new strategies in teaching education Mathematic and improving students' achievement in mathematics especially algebra while minimizing mental effort.

Keywords Algebra Tiles, conceptual knowledge, mental effort, procedural knowledge, Quadratic Equations.

INTRODUCTION

Mathematics is one of the most important subjects in the education system in Malaysia. The importance of mathematics is clear when it appears as a core subject that compulsory to be taken in public examinations in Malaysia. However, many students perceive that Mathematics subject is so difficult to understand and contains many abstract concepts. This causes students to not be interested in this subject like other subjects and subsequently affects their understanding of mathematical concepts [1].

Haryanti et al. [2] stated that in learning Mathematics subjects, a student needs to master both conceptual and procedural knowledge. This is because without these two knowledges, students will not be able to understand mathematical concepts in details. If a student only masters the conceptual knowledge without procedural knowledge, the student will not be able to solve math problems correctly and well. Whereas, if a student only has procedural knowledge without conceptual knowledge, they are only able to solve mathematics problems without being able to understand and interpret the meaning behind the problems. Conceptual knowledge can be measured when a student knows what he is doing and why he needs to do it [3]. A student is considered to have achieved conceptual knowledge when he is able to answer each question correctly or can explain how the calculation procedure was done. The procedural knowledge is a person's ability to perform a sequence of objects, arithmetic calculations and step-by-step order to solve a problem [4] or a knowledge to know how to perform a task or activity that requires a certain action [5]. However, a study carried out by Manandhar et al. [6] has found that most of the students are more inclined to memorize the procedure of calculation steps to solve mathematical questions rather than to understand the mathematical concept itself. This causes students to face difficulties in solving mathematics questions if the questions asked are different from those memorized by students.

The results of the study carried out by Baring and Alegre [7] showed that among the mathematical topics that are considered difficult, and challenging is the topic of Quadratic Equations and students' achievement for this topic is still at a low level [8]. The findings of the study by Utami and Jupri [9] also showed that there are still many students who make mistakes in solving problems involving quadratic equations. Apart from problems in solving quadratic equations, students often think that mathematics class, especially for Algebra topics, is one of topics with full of procedures and rules that must be memorized to answer algebraic questions.

In recent study by Salifu [10] has found that the effectiveness of the Algebra Tiles and the study also recommended teachers should use the Algebra Tiles in the teaching and learning of linear equations in one variable because it will help improve performance in mathematics. This study only focuses on implementation Algebra Tiles in linear equations in one variable only. In addition, this Algebra Tiles method not only has a positive impact on secondary school students but also has a good effect on university students. The study by [11] found that the virtual Algebra Tiles method conducted on 40 university students in Colombia is a very suitable alternative pedagogical tool for learning more clearly about Algebra, especially in secondary schools and universities, as it allows students to actively engage in class and is capable of building Mathematical knowledge. Therefore, in this study, a concrete manipulative Algebra Tiles was used to be implemented in teaching and learning the topic of Quadratic Equations.

Cognitive load theory states that learning complex cognitive skills such as problem solving is often limited by limited information processing capacity [12]. According to [13], the learning process can be hindered if a learning activity requires cognitive capacity that exceeds its limits. Therefore, learning strategies that maximize the use of cognitive resources are very important in ensuring the effectiveness of the strategies used. A lack of cognitive resources in learning strategies will cause cognitive activities not to be implemented in working memory and will subsequently result in the learning process being hindered and failing. Mental effort is an aspect of the cognitive load experienced by a person as a result of the task demands imposed on him and the mental effort performed reflects the actual cognitive load [14]. Mental effort is measured when students work on a task or test by using their own ranking scale. Some important information related to cognitive load based on measurement of mental effort can be obtained compared to measurement of mental load and achievement.

According to Lenz et al. [15], most teachers place more emphasis on memorizing formulas, calculation steps or procedures to solve problems in mathematics than encouraging students to think creatively and critically in solving mathematical problems so that students can use their potential to build more meaningful conceptual knowledge. In this era of globalization, the learning process is not just focused on the use of textbooks, or the use of chalk and whiteboards. Therefore, teachers need to be wise in choosing teaching methods that are appropriate for the level of student acceptance in order to produce knowledgeable individuals. One of the most effective strategy in conveying abstract concepts is to use concrete materials. By providing physical representations through manipulative tools in the teaching and learning (T&L) process, it can provide better understanding for students who have difficulty understanding abstract concepts in mathematics. Therefore, students have built a strong conceptual foundation before developing higher mathematical thinking [9]. Among the manipulative tools that can help students to have better understanding of abstract concepts in mathematics, especially in algebra, is the Algebra Tiles.

Algebra Tiles began with the basic idea of using manipulative materials to represent algebraic concepts by Zoltan Dienis and its use was further developed by Mary Laylock and Peter Ramussen [16]. Manipulatives have the potential to teach challenging concepts like algebra [16]. Furthermore, according to [17], manipulatives tools can be used as a learning tool to achieve learning objectives. Algebra Tiles is one of the manipulatives. In addition, the use of concrete teaching materials like Algebra Tiles is very important in the introduction of mathematical concepts [18]. Algebra Tiles are rectangular shaped tools consisting of blue and red colors that can be used to represent variables and integers in algebra. Algebra Tiles are used to build concrete representations for abstract areas in algebraic concepts. Concrete representations can help to enhance student understanding through the use of symbols to represent algebraic concepts. Algebra tiles are commonly used for exploring integers, algebraic expressions, quadratic equations, quadratic factorization, and algebraic expansion. An example of an Algebra Tile design is shown in Figure 1.

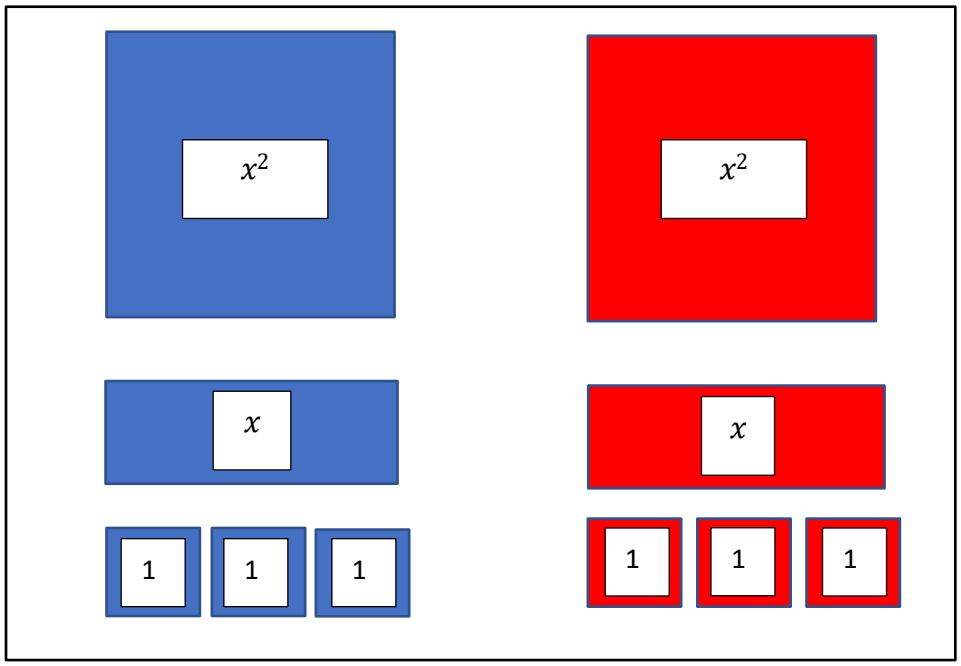

Figure 1 Algebra Tiles Design

In this study, the use of Algebra Tiles is expected to reduce the cognitive load required in solving quadratic equations through a correct understanding of algebra concepts. The sample of this study consisted of Form Four students who are Generation Z, where this generation needs a new approach in T&L sessions at school. A study by [20] stated that Generation Z easily learns knowledge through watching, observing, seeing and listening to actions, events through moving pictures or concrete visuals. For Generation Z, they are more inclined towards technological or virtual and practical learning.

Therefore, based on the above background, this study was conducted among Form Four students to achieve the following objectives:

i. to determine the effect of using Algebra Tiles on the overall achievement for the topic of Quadratic Equations,
ii. to determine the effect of using the Algebra Tiles on conceptual knowledge for the topic of Quadratic Equations,
iii. to determine the effect of using Algebra Tiles on procedural knowledge for the topic of Quadratic Equations,
iv. to determine the effect of using Algebra Tiles on students' mental effort for the topic of Quadratic Equations.

RESEARCH METHODOLOGY

This study is a quantitative study which using a quasi-experimental design. The quasi-experimental design is chosen since this design is appropriate for studying the effectiveness of interventions and also very suitable for studies involving experiments [21]. This study used the achievement tests as a measurement tool. The independent variable in this study is the T&L method that uses Algebra Tiles and the conventional method for

the topic of solving Quadratic Equations, while there are four dependent variables namely overall achievement, conceptual and procedural knowledge achievement and mental effort.

Table 1 Quasi-experimental Study Design

Group	Pre Test	Teaching	Post Test
Experiment Group	O_1	X_1 (PJA)	O_2
Control Group	O_3	X_2 (PK)	O_4

The sample was divided into two groups, namely the control group and the experimental group. The control group will undergo conventional Quadratic Equation learning (PK) while the experimental group underwent Quadratic Equations learning using Algebra Tiles (PJA) for eight weeks. The selection of four classes from seven classes to form two experimental groups (PJA) and two control groups (PK) was done simple random sampling by using the *Fish-bowl* method. All the seven classes are organized by the school according their achievement in their latest examination. Table 1 shows the design for this study. In this quasi-experimental study, the sample of the study consisted of 120 students from one national secondary school in Shah Alam district, Selangor, Malaysia. In order to ensure homogeneity of ability levels between students, the recommendations by [22] also has been considered for the class selection. Both control groups and experimental groups is taught by the same teacher who experience in teaching Mathematics. The PJA group and the PK group have undergone the pre-test, O_1 and O_3, respectively before undergoing the Algebra Tiles learning and conventional learning to determine whether the abilities of the two groups are the same or different. After the learning process of these two groups are conducted, the sample underwent the post-test (O_2 & O_4) to assess the level of their overall achievement on topic of Quadratic Equations, the achievement of procedural and conceptual knowledge and their mental effort.

There are two instruments used in this study, namely the Quadratic Equations Achievement Test (UPPK) and the Mental Effort Proportion Scale (SPUM). This UPPK consists of 6 subjective questions adapted and modified from [23] and [25] which aims to test students' conceptual knowledge level and procedural level according to Bloom's Taxonomy level for the topic of Quadratic Equations. The SPUM instrument is adapted from [25] which was used to measure the level of student's mental effort in solving mathematical questions in the UPPK instrument that involves the level of conceptual and procedural knowledge. SPUM consists of a nine-point Likert scale as given in [26] that starts from scale 1 for a lowest mental effort to scale 9 for a highest mental effort. The 9 Likert scale in SPUM instrument is explained to the sample before the study is conduct. All instruments have gone through the process of expert validation and the finding from the pilot study showed that pre-test UPPK obtained Cronbach's alpha value 0.81 while post-test UPPK obtained Cronbach's alpha value 0.80. The Cronbach's alpha values obtained show that the instruments have acceptable and convincing reliability values that exceed 0.70 as stated in [27].

The descriptive statistics involving mean and standard deviation were determined to summarize the distribution of PK and PJA achievement scores. Subsequently, MANOVA statistical analysis was conducted to analyze whether significant difference existed between PK and PJA groups in terms of students' overall achievement, conceptual and procedural knowledge achievements and students' mental effort. Prior to the learning session, exploratory data analysis was performed to confirm that both PK and PJA groups were homogeneous regarding their prior achievement in the topic of Quadratic Equations. Furthermore, all assumptions required for the MANOVA test were checked to ensure the validity of the analysis.

RESULTS AND DISCUSSION

The analysis and discussion of the four research questions to achieve the research objectives that have been stated are given as follows.

Research Question 1: Is there a significant difference in mean overall achievement on pre-test and post-test scores in solving quadratic equations between experimental and control group?

For the standard deviation as shown in Table 2, the pre-test results give similar levels of variability between PK and PJA groups, with the PJA group shows slight lower variability (SD=5.23) compared to the PK group (SD=5.68). Furthermore, the mean value obtained by the PK group is slightly higher (36.70) compare to mean value obtained by PJA group (35.50). In addition, Table 2 shows that the experimental group, PJA (using Algebra Tiles teaching) has a higher mean score (76.87) compared to the control group, PK (conventional teaching) which had a mean score of 65.70. The results indicated that students' overall achievement with Algebra Tiles teaching increased compared to the conventional teaching. Both groups experience an increase in score variability for the post-test, but the PJA group (SD=5.95) maintained slightly more consistent performance than the PK group (SD=6.41). Hence, it can be seen that the learning approach underwent by PJA group not only led to higher mean score but also resulted more consistent outcomes among students.

Table 2 Descriptive analysis of overall achievement on pre-test and post-test scores

	Variable	Group	N	Mean	Standard deviation
Pre-Test	Overall achievement	PK	60	36.70	5.68
		PJA	60	35.50	5.23
Post-Test	Overall Achievement	PK	60	65.70	6.41
		PJA	60	76.87	5.95

Apart from that, the results of the MANOVA analysis indicated a significant difference in overall achievement between the PK group and the PJA group with p-value = 0.00 < 0.05 (threshold) (Table 3). Therefore, the analysis of the study shows that the PJA approach can enhance the students' mastery in understanding and solving algebraic problems on the topic of Quadratic Equations. From Table 3, the partial Eta squared value obtained is 0.45 which indicates the effect size between the variables is large.

Table 3 MANOVA analysis of overall achievement on pre-test and post-test scores

Source	Dependent variables	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
Group	Overall achievement	3740.83	1	3740.83	97.80	0.00	0.45

The results of this study confirmed finding for previous study conducted by Larbi and Okyere [28] which showed the effectiveness of Algebra Tiles manipulative material on the overall achievement of 56 students in one of the secondary schools in Ghana. The results of the study have shown that there was a significant difference

in the mean overall achievement of Mathematics for the treatment group (mean = 3.96) compared to the control group (mean = 0.84). This shows that the mean obtained by the treatment group is higher compared to the control group that was taught by conventional through "talk and chalk" teaching. Next, the results of this study are also in line with the results obtained in the quasi-experiment conducted by [29], [30] and [31] which found that Algebra Tiles act as a teaching aid that can help students to better understand the concept of algebra.

Research Question 2: Is there a significant difference in the mean achievement of conceptual knowledge on the pre-test and post-test scores in solving the quadratic equations test between experimental and control group?

The descriptive analysis in Table 4 indicates that the mean value of the post-test for PJA group (20.75) has a higher mean than the PK group (18.10), showing that the PJA group with Algebra Tiles teaching approach performed better in conceptual knowledge compared to the PK group with conventional teaching. In terms of standard deviation, the pre-test values in score for the PJA group (SD=2.52) show slightly less variability compared to PK group (SD=2.83). However, both groups showed similar levels of score consistency in the post-test, PJA with SD=1.87 and PK group with SD=1.80. Overall, the PJA group achieved higher conceptual knowledge and both groups displayed consistent performance levels within their respective group.

Table 4 Descriptive analysis of conceptual knowledge achievement on pre-test and post-test scores

	Variables	Group	N	Mean	Standard deviation
Pre-Test	Conceptual knowledge	PK	60	12.57	2.83
		PJA	60	12.12	2.52
Post-Test	Conceptual knowledge	PK	60	18.10	1.80
		PJA	60	20.75	1.87

The results of the MANOVA analysis indicated a significant difference in overall achievement between the PK group and the PJA group with *p*-value = 0.00 < 0.05 (threshold) (Table 5).

Table 5 MANOVA analysis of conceptual knowledge achievement on pre-test and post-test scores

Source	Dependent variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
Group	Conceptual knowledge	210.68	1	210.68	62.36	0.00	0.35

The result of this study is in line with the study conducted by [32] which showed that the use of the Algebra Tiles strategy is able to reduce the common mistakes made by students in solving algebra problems involving one variable. From Table 5, the partial Eta squared value obtained is 0.35 which indicates the effect size between the variables is large. This shows that a correct conceptual understanding can reduce the common mistakes that are made by students.

Besides, it can be seen that the use of Algebra Tiles is also a very effective teaching approach, can have a positive impact on the understanding of algebra concepts among students and also can help in improving the thinking of solving algebraic problems and algebraic concepts. This can be proven through the results of a study

by [28]. The results of the study by [33] have shown that the use of virtual Algebra Tiles can be used as an alternative pedagogical tool that can be used in explaining the concept of algebra in addition to creating an active learning atmosphere among students. The results of their study also found that Algebra Tiles can also help students build mathematical knowledge, especially knowledge in algebraic concepts.

A study by Kaya [34] has shown that most of the teachers agreed that Algebra Tiles can help in improving student's conceptual and procedural knowledge of algebra. Most teachers also suggested that Algebra Tiles should be introduced more widely to students and teachers in the process of T&L Mathematics. Therefore, the use of Algebra Tiles in the T&L process, especially for the topic of Quadratic Equations, can improve students' conceptual knowledge in understanding the concepts of algebra and quadratic equations.

Research Question 3: Is there a significant difference in the mean achievement of procedural knowledge on the pre-test and post-test scores in solving the quadratic equations test between experimental and control group?

The descriptive analysis of student's procedural knowledge achievement based on the pre-test and post-test scores in solving the quadratic equations test for both experimental and control groups is given in table 6. For the pre-test, both PK and PJA groups showed similar variability with standard deviation of PJA group (SD=2.56) slightly lower than PK group's standard deviation (SD=2.64). For the mean value for pre-test obtained by PK group (5.78) is slightly higher than the mean pre-test obtained by PJA group (5.63). Furthermore, it can be seen that the mean value for post-test obtained by the PJA group (17.67) is higher than mean post-test score for PK group (14.87). Regarding of standard deviation, the PJA group indicates a relatively lower post-test variability (SD=1.73) compared to PK group (SD=2.04). The results of this study recommend that the PJA group has higher mean post-test score and demonstrated more consistent performance compared to the PK group.

Table 6 Descriptive analysis of procedural knowledge achievement on pre-test and post-test scores

	Variables	Group	N	Mean	Standard deviation
Pre-Test	Procedural knowledge	PK	60	5.78	2.64
		PJA	60	5.63	2.56
Post-Test	Procedural knowledge	PK	60	14.87	2.04
		PJA	60	17.67	1.73

Table 7 shows the result of MANOVA analysis, indicates a significant difference in procedural knowledge achievement between the PK group and the PJA group with p-value = 0.00 < 0.05 (threshold). From Table 7, the partial Eta squared value obtained is 0.36 which indicates the effect size between the variables is large. This suggests that the intervention of Algebra Tiles teaching for the PJA group led to statistically significant improvement in the procedural knowledge achievement compared to the conventional teaching for PK group.

Table 7 MANOVA analysis of procedural knowledge achievement on pre-test and post-test scores

Source	Dependent variables	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
Group	Procedural knowledge	235.20	1	235.20	65.73	0.00	0.36

The result of this study is in line with the study carried out by [11] which showed that the level of achievement of students' procedural knowledge increases and also suggested the use of concrete materials such as Algebra Tiles in teaching can help students in understanding algebra concepts. Magruder [35] has stated that the use of concrete manipulative tools Algebra Tiles is more effective in providing procedural knowledge in algebra. The results of the study in [28] have found that students have given a positive response from the aspect of procedural algebra knowledge when using Algebra Tiles during mathematics learning. In conclusion, the use of Algebra Tiles can increase students' procedural knowledge in solving quadratic equations. Not only that, the Algebra Tiles can also be used as a concrete material that provide the correct visualization to students in the T& L process for the topic of Quadratic Equations.

Research Question 4: Is there a significant difference in the mean achievement of students' mental effort on the pre-test and post-test scores in solving the quadratic equations test between experimental and control group?

Table 8 gives a descriptive analysis of the mean value for students' mental effort on the pre-test and post-test scores in solving the quadratic equations test between the experimental and control groups. Based on the 9-point scale of mental effort outlined in [26], it can be seen that the PJA group is reported used lower mental effort when answering the UPKK post-test questions, with mean score of 4.92, compared to the PK group which showed with higher mean score of 7.45. In terms of standard deviation, the PJA group demonstrated their mental effort consistently with the standard deviation SD=0.13 for both pre-test and post-test, while the PK group showed slightly less variability in their post-test mental effort (SD=0.09), with a pre-test standard deviation of 0.15. The result of this study shows that the PK group needed more mental effort in solving the quadratic equation test, compared to the PJA group, which the latter showing more consistent effort levels across both tests.

Table 8 Descriptive analysis of student's mental effort on pre-test and post-test scores

	Variable	Group	N	Mean	Standard deviation
Pre-test	Mental effort	PK	60	7.03	0.15
		PJA	60	7.04	0.13
Post-test	Mental effort	PK	60	7.45	0.09
		PJA	60	4.92	0.13

The MANOVA analysis showed a significant difference in student's mental effort between the PK group and the PJA group with a significant value of p-value = 0.00 < 0.05 (Table 9). From Table 9, the partial Eta squared value obtained is 0.99 which indicates the effect size between the variables is large.

Table 9 MANOVA analysis of students' mental effort on pre-test and post-test scores

Source	Dependent variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
Group	Mental effort	192.20	1	192.20	14267.40	0.00	0.99

Based on the results of this study, it can be seen that the Algebra Tiles teaching approach in PJA has a great impact on students' achievement in solving questions for the topic of Form Four Quadratic Equations. In addition, the findings of this study also showed that this learning approach can provide a positive effect on mental effort in solving UPKK questions and can be used as an alternative teaching method to the conventional method, which is PK.

A study by [36] has found that the use of Algebra Tiles as a physical manipulative tool can help students in Indonesia in solving linear equations of one variable. Therefore, the results also showed that the use of Algebra Tiles in the classroom is able to illustrate the abstract concepts of algebra that are deeper and more meaningful in solving linear equations of one variable.

CONCLUSION

As a conclusion, the results of the study showed that there was a significant difference between the group that used conventional teaching (PK) and the group that used Algebra Tiles teaching (PJA) on students' overall achievement, conceptual achievement, procedural knowledge achievement and mental effort. The results of the study showed that the overall achievement, conceptual knowledge achievement and procedural knowledge achievement of the PJA group has a higher mean compared to the PK group. In addition, the results of the study have also shown that the PJA group has a higher achievement with the use of low mental effort when answering the post-test UPKK questions. This showed that PJA has a positive effect on mental effort in solving quadratic equations. The use of Algebra Tiles in the T&L process greatly helps students in building conceptual and procedural knowledge in solving questions on the topic of Quadratic Equations. Through the use of Algebra Tiles, students can differentiate and understand the concepts and procedures of the topic of Quadratic Equations. In addition, the use of Algebra Tiles can also reduce cognitive load in solving quadratic equations problems. The implication of this study is that the Algebra Tiles can be used as an interesting teaching strategy that can help students' understanding in the process of T&L mathematics. Furthermore, the implication of this study is that teachers have traditionally changed their teaching practices to teach using Algebra Tiles in classroom which is more student-centered and in line with 21st century teaching. Further research can be done by implement the Algebra Tiles in other subtopic of Mathematics such as addition and subtraction in algebraic, positive and negative integers, multiplying two algebraic expression and so on.

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