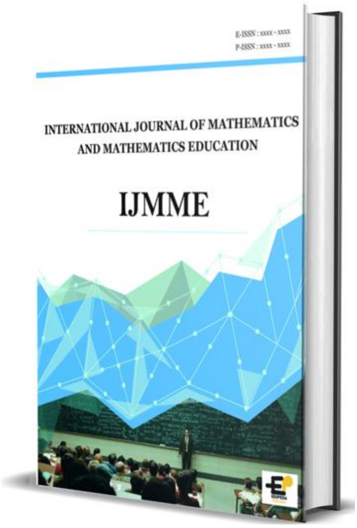

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The Effects of Virtual Algebra Tiles on the Performance of Year 8 Students in Solving Algebraic Linear Equations

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Abstract

This study aims to examine the effects of Virtual Algebra Tiles (VAT) on the performance of 41 Year 8 students in solving algebraic equations. The VAT used in this research is accessible and free through a website called Didax. Quantitative and qualitative data were collected from Class 8X (21 students) and Class 8Y (20 students) through convenient sampling in a public secondary school. The Didax VAT was used as an intervention tool to aid students in solving algebraic equations. Quantitative data, in the form of pre-test, post-test, and questionnaire, was administered to the students and analysed to determine the statistical significance of the findings. Qualitative data were used in focus group interviews to explore students' perceptions of Didax VAT further. The conclusions of this study indicated that the result of the paired sample t-test was not significant, the intervention had a small positive effect on student learning. The qualitative data revealed most students positively perceived using Didax VAT in their learning.

Introduction

Rooted under Piaget's theory of cognitive development, manipulatives such as algebra tiles can be a means for learners to explore concepts in the 'concrete operations stage' by drawing connections between concrete representations and abstract ideas (Ojose, 2008). Piaget's theory of cognitive development states that children learn best through active engagement, as algebra tiles can help students visualise abstract concepts in mathematics education. Fundamental research has affirmed that the use of modelling tools in Mathematics has led to significant increases in students' overall achievements (Moyer-Packenham & Suh, 2012; Chong & Shahrill, 2016; Abdul Latif et al., 2024; Chong et al., 2018, 2019; Bouck et al., 2020; Khalid & Embong, 2020). Manipulatives such as algebra tiles are modelling tools designed to aid students in understanding mathematical concepts (Moyer-Packenham & Suh, 2012) by transforming abstract concepts into comprehensible concrete representations (Khalid & Embong, 2020).

Mathematics manipulatives can also be used in teaching to help students learn mathematics more engagingly and enjoyably (Morsidi & Shahrill, 2015; Furner & Worrell, 2017; Sahat et al., 2018; Amarasena & Adnan, 2023; Mohd Apandi & Adnan, 2023; Muhammad & Adnan, 2023; Supian et al., 2023). This is also synonymous with findings from Carbonneau et al. (2013), which revealed that incorporating manipulatives in mathematics lessons significantly affected student learning compared to lessons that only used abstract symbols. According to Rini (2022), using algebra tiles has reduced students' difficulty in solving algebraic problems. Her study also found that not only can it reduce students' difficulties in solving linear equations, but using algebra tiles can also make students more enjoyable in learning mathematics. As shown in Figure 1, algebra tiles consist of various sizes of two-dimensional rectangular shapes representing constants, values and variables in mathematics. The positive coefficient of x^2, x, and the positive constant 1 represent a blue, green, and yellow tile. Represented with a red tile are the negative coefficient of x^2, x and the negative constant one.

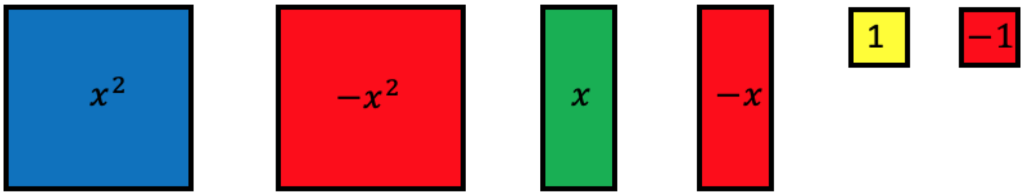

Figure 1. A Set of Algebra Tiles

Abdul Latiff et al. (2017) examined using algebra tiles to aid low-performing students in understanding how to factorise quadratic expressions. Their findings show that students' achievement increased after the intervention. A study by Larbi and Okyere (2014) also revealed that through the extensive use of algebra tiles, students were able to perform significantly better. However, Moyer-Packenham and Suh (2012) argued that concrete representations can only help clarify mathematical concepts if they serve as a tool to interpret reality rather than as an end product. In other words, concrete representations such as algebra tiles should help establish connections between real-life and abstract mathematical problems. Although the significant effect of algebra tiles in assisting students to understand mathematical concepts is recognised, there are several challenges and drawbacks. Salifu (2022) noted that inadequate resources, the high cost of algebra tiles, and the extended preparation time are among the challenges of using algebra tiles in classrooms. In addition, the lack of professional training and the unavailability of user guides on algebra tiles can lead to teachers' hesitation in using it when teaching (Salifu, 2022).

While there has been extensive research on using manipulatives to aid students' performance in mathematics, there is a significant gap in the study of virtual manipulatives and their potential impact(s) on student learning. Much of the existing research provided the theoretical framework of virtual manipulatives (Durmus & Karakirik, 2006; Sarama & Clements, 2016), whilst other studies focused on the importance of virtual manipulatives aiding low-achieving students (Moyer-Packenham & Suh, 2012), students with learning disabilities (Bouck et al., 2020), and local studies using virtual manipulatives on fractions (Finti et al., 2016; Abdul Latif et al., 2024), and integers (Goh et al., 2017; Ismail et al., 2023).

Durmus and Karakirik (2006) provided a theoretical framework for incorporating virtual manipulatives in mathematics education, outlining how manipulatives such as algebra tiles are used effectively in classrooms and highlighting how they can help students learn. At the same time, Sarama and Clements (2016) compared physical and virtual manipulatives to examine their effectiveness. They concluded that both manipulatives enhance learners' mathematical thinking by developing their 'integrated-concrete knowledge'.

Moyer-Packenham and Suh (2012) also examined the effects of virtual manipulatives on different types of achievement groups. They concluded an overall significant increase in students' achievement, with low-achieving students benefitting the most. Hence, categorising the students according to ability and investigating the effects of virtual manipulatives on each group can give further insights into the impact of the intervention. Bouck et al. (2020) studied how virtual manipulatives can support students with learning disabilities. Using qualitative methods, the researchers presented four vignettes where virtual manipulatives are used in classrooms to teach basic number operations, fractions, and algebra. However, it should be noted that although this research provides concrete examples of how virtual manipulatives are used, it does not demonstrate the effectiveness of virtual manipulatives in improving students' understanding and achievement of the mathematical subject.

While there has been extensive research on the general use of manipulatives to enrich student learning, as demonstrated in previous sub-sections, literature on Virtual Algebra Tiles (VAT) needs to be more prominent. Nonetheless, several relevant works of literature are highlighted in this section to give an overview of the existing research surrounding the topic. For instance, Garzòn and Bautista (2018) conducted research to evaluate the effectiveness of VAT in enhancing engineering undergraduates' knowledge of algebra concepts. They concluded that the tool has a significant effect size on students' knowledge retention and learning effectiveness. This research focused on engineering undergraduate students who may have been exposed to using algebra tiles at the primary or secondary level. The changes in students' achievement might not be due to the intervention. Therefore, extraneous variables may affect the outcomes, threatening the study's internal validity (Efron & Ravid, 2013).

Teck (2013) investigated the usefulness of VAT in developing secondary students' conceptual understanding of algebra by employing qualitative methodology in the form of interviews. Although favourable results were seen, the researcher did not elaborate and provide detailed information on certain parts of the methodology section. In particular, it was unclear why only 15 students (or 7% of all participants) were interviewed when 207 students participated. Moreover, the trustworthiness of the data collected can be further enhanced through triangulation, whereby more than one method is used to obtain information to gain varied perspectives (Efron & Ravid, 2013). With that said, and as far as is known, no existing literature has investigated the effectiveness of VAT and its causal-effect relationship with students' achievement, particularly in solving linear algebraic equations and understanding students' perceptions of VAT using mixed methods. Hence, the gap in research surrounding VAT remains as more empirical evidence surrounding VAT is needed. The results of this study will contribute widely to the literature relating to VAT and the effect of its usage in Mathematics education.

This present study examines the efficacy of using virtual manipulatives, specifically algebra tiles, to improve students' skills in solving algebraic linear equations. The potential effects of using virtual manipulatives, specifically VAT, to aid students in performing better in algebra are explored in this research. The VAT used in this research is a browser-based manipulative that is easily accessible through the Didax website (https://www.didax.com/math/virtual-manipulatives.html) and is entirely free to use. It does not require any form of subscription or registration. It is considered a reliable source for virtual manipulatives as the company specialises in producing mathematics manipulatives and software. The following research questions guided this study: 1) How does using Didax VAT affect Year 8 students' performance in solving algebraic linear equations? And 2) how students perceive Didax VAT when learning to solve algebraic linear equations.

Method

This study used a mixed-method design, where both qualitative and quantitative data were collected. A mixed-method design was deemed appropriate to answer the multifaceted research questions in the study. The quantitative data collection allowed the study to explore the significant effect of VAT in influencing students' achievements, answering the first research question. To answer the second research question, qualitative data was collected to explore the students' perception of VAT. Incorporating both methods provided a more nuanced, robust and comprehensive understanding of the research problem. The participants were selected based on a convenient sampling of Years 8X and 8Y classes, with 41 students in a government or public secondary school in Brunei Darussalam. The Didax VAT was used in the intervention lessons. The intervention was carried out in three consecutive 50-minute lessons. The first intervention lesson focused on introducing Didax VAT, and the second and third lessons concentrated on solving one- and two-step algebraic linear equations using Didax VAT, respectively.

Figure 2 shows how the Didax VAT can solve an algebraic linear equation $2x - 4 = 2$. The first step involves representing each variable accordingly. A positive constant/integer (+1) is represented by a yellow square tile, whereas a negative constant/integer (-1) is represented by a red square tile. Meanwhile, a green rectangular tile represents the positive coefficient of x ($1x$), and a red rectangular tile represents a negative coefficient of x ($-1x$). In this example, the equation $2x - 4 = 2$ is modelled by two green rectangular tiles, four red square tiles on the left, and two yellow square tiles on the right. Step 2 involves adding four yellow square tiles on each side of the equation to create a zero pair on the left-hand side. Step 3 consists of removing the zero pair to show $2x = 6$. Lastly, step 4 involves making two equal tiles on the right-hand side to reveal that $x = 3$.

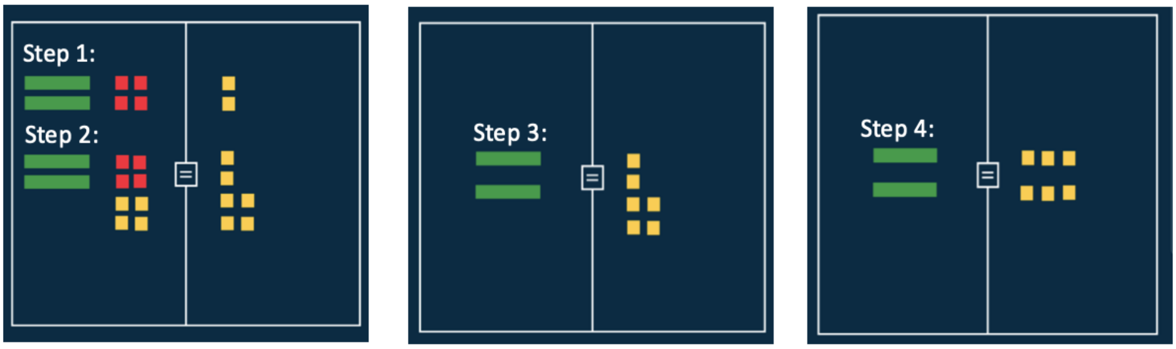

Figure 2. An Example of How Didax VAT is Used to Solve $2x - 4 = 2$

The Didax website was preloaded beforehand on the students' computer in the school's ICT lab to ensure that the time was used efficiently during the lesson, and the teacher modelled how to use the Didax VAT through the projector in front of the room. The first lesson focused on introducing VAT using Didax as a digital learning tool. Students were taught how to model algebraic linear equations using Didax VAT. Figure 3 shows samples of students' work where they were asked to model the equation $2 - 5x = 12$. Most students could show their understanding of the concept learned by placing two yellow square tiles, five red rectangular tiles on the left side, and twelve yellow squares on the right side of the equation. Additionally, students also enjoyed positioning the tiles in a variety of ways. However, some students made the mistake of placing five green rectangular tiles as they were confused with the colour representation of the tiles.

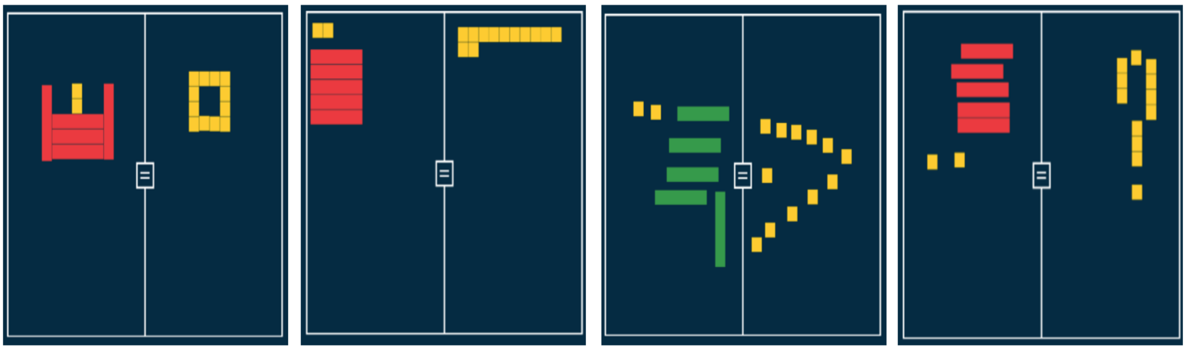

Figure 3. *Samples of Students' Work During the First Intervention Lesson*

The following second and third intervention lessons showed students how to use Didax VAT to solve algebraic linear equations. Figure 4 shows a sample of students' work attempting to solve the algebraic equation $2x - 3 = 7$. The students modelled the equation using Didax VAT by dragging the selected tiles to the provided space in pairs. After that, they created zero pairs by adding three yellow tiles on the left-hand side of the equation. Simultaneously, they said the same number of yellow tiles on the right-hand side of the equation. After removing the zero pairs, they arranged the remaining tiles by making two groups of equal numbers of sides to reveal that $x = 5$.

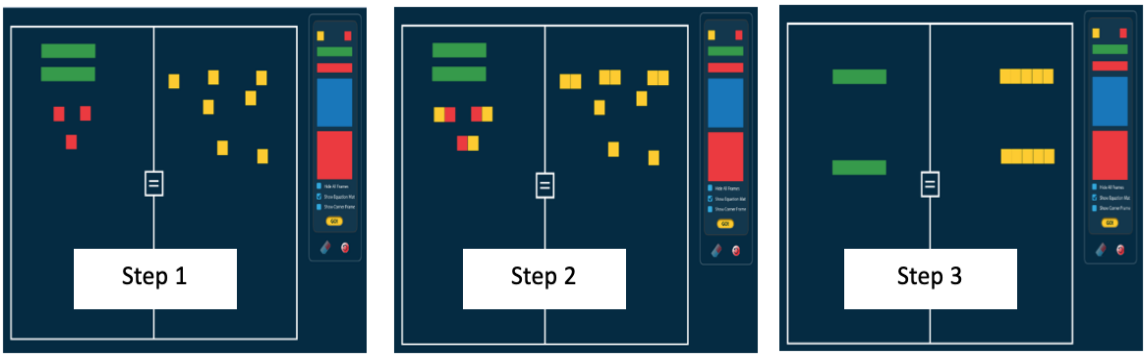

Figure 4. Sample of Students' Work During the Third Intervention Lesson

The pre-test was given to the participants before the start of the first intervention lesson. Participants were given ample time to answer the questions without using calculators. Each question ranged from easy to complex, with a minimum of one mark for solving two-step equations and a maximum of two marks for solving three-step equations. The maximum total score for the test was 16 marks. A week after the intervention lessons were completed, the post-test was administered to the participants under the same conditions as the pre-test (refer to Appendix A). However, the order of the questions was reorganised to prevent students from recalling the answers in order from the pre-test. After the pre-test and post-test were marked, a statistical analysis was conducted to examine the effects of Didax VAT on students' achievements. The questionnaire (Appendix B) was administered after the post-test for the participants to complete. Students were required to answer all the questions.

Using R Studio, the quantitative data from the pre-test and post-test was analysed for descriptive statistics, including central tendency and variability measures. The results were used to determine whether to accept or reject the null hypothesis of the first research question as follows:
Null Hypothesis (H_0): Virtual algebra tiles do not significantly affect Year 8 students' performance.
Alternative Hypothesis (H_1): Virtual algebra tiles significantly affect Year 8 students' performance.

Analysis of the graphical representations in the form of histograms and Q-Q plots was also done in tangent with the Shapiro-Wilk test to assess the normal distribution of the data. If the data is normally distributed, the quantitative data will be analysed using a parametric procedure: the paired sample *t*-test. Conversely, if the assumptions of normality are not met with the data not normally distributed, a non-parametric procedure, the Wilcoxon signed-rank test, will be conducted. The paired sample *t*-test or Wilcoxon signed-rank test will be used to determine if there is a statistically significant ($P < 0.05$) improvement between the pre-test and post-test marks, thereby denoting that the intervention lessons using Didax VAT will positively affect the student's academic performance. Using R Studio to calculate the partial eta square effect size will determine the strength of association or the magnitude of the difference between the means pre-test and post-test results (Tabachnick & Fidell, 2007).

The quantitative and qualitative data collected from the questionnaire and focus group interviews (Appendices B and C) were analysed separately to address the second research question. A descriptive statistical analysis of the 10-item response from Likert-scale questions was done in R Studio. The answers to the open-ended questions in the questionnaire and focus group interviews were transcribed, coded, and analysed to reveal themes in the textual data. The thematic analysis was conducted using the guidelines outlined by Braun and Clarke (2006). The qualitative analyses of the questionnaire and focus group interviews revealed insights into the students' perceptions of the effectiveness of the Didax VAT in learning how to solve algebraic equations. The study's purposeful quantitative and qualitative findings were brought together to form a panoptic view of the effects of VAT concerning student achievement and perception.

Results

Evaluating the Effects of Didax VAT on Students' Performance

As displayed in Table 1, the results of the descriptive statistics of the pre-test scores for Year 8X (M = 6.76, SD = 4.64) for Year 8X were slightly lower than for Year 8Y (M = 8.60, SD = 4.02). After the intervention lessons were completed, there were observable differences in students' performance in the post-test scores for Year 8X (M = 7.10, SD = 3.91) and Year 8Y (M = 10.2, SD = 2.86).

Table 1. Descriptive Statistics of Pre-test and Post-test Scores for Years 8X and 8Y

		Mean			Standard Deviation	
	N	Pre-test	Post-test	Mean Difference	Pre-test	Post-test
Year 8X	21	6.76	7.10	0.34	4.64	3.91
Year 8Y	20	8.60	10.2	1.60	4.02	2.86

Figure 5 shows the line graph that compares the marks obtained by the students in the pre-test and post-test. It shows a general shift to the right of the graph, indicating that most students achieve higher marks in the post-test than in the pre-test. The peak also shifted from a total mark of 7 in the pre-test to 12 in the post-test. It was also observed that the number of students who obtained 0 marks decreased from 3 to 0.

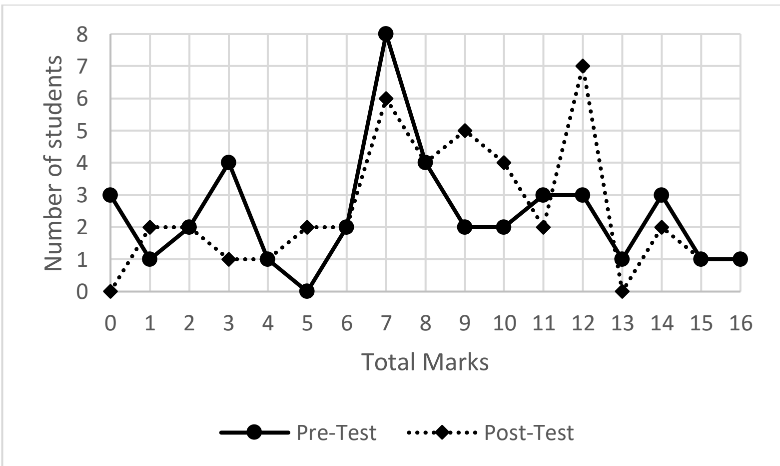

Figure 5. Comparison of the Students' Marks in the Pre- and Post-tests

Due to the small sample size (n = 41), it was critical to determine the distribution of the mean marks to choose the appropriate statistical method. Therefore, a Shapiro-Wilk test was conducted, and the results showed no evidence of non-normality (W = 0.98, p-value = .723). Visual assessment of the histogram also showed no evidence of non-normality with the skewness value of -0.0325. The Q-Q plot observed had no clustering of points, and the boxplot did not identify any outliers. Moreover, Levene's test shows that the p-value is .0962 (> 0.05), indicating that the assumption of homogeneity of variance has been met. Based on these preliminary analyses and following the assumption of normality, the parametric procedure, the paired sample *t*-test to compare the pre-test and post-test mean scores was conducted for all samples (n = 41). The null hypothesis states that there is no significant effect of Didax VAT on Year 8 students' performance and is rejected if the significance level is less than 0.05 (p-value < .05). Conversely, the null hypothesis is accepted if the significance level is more than 0.05 (p-value > .05).

Table 2 shows the statistical results of the analysis done in R studio. Overall, there was no statistically significant increase in the test scores from the pre-test (M = 7.66, SD = 3.74) to post-test (M = 8.61, SD = 3.74) conditions; t (40) = 1.71, p = .0945 in two-tailed. The increase in the mean scores was 0.951, with a 95% confidence interval range of -0.171 to 2.07. Given that p =. 0945, the null hypothesis is accepted and shows that the Didax VAT intervention did not significantly affect Year 8 students' performance in solving algebraic linear equations.

Table 2. Paired Sample T-test for All Year 8 Students

The paired differences								
Classification	Mean	Standard Deviation	Standard Error Mean	95% Confidence Limit		t	df	Sig(two-tailed)
				Lower	Upper			
All Year 8	0.951	3.55	0.555	-0.171	2.07	1.71	40	0.0945

Understanding Students' Perceptions of Didax VAT

Cronbach's alpha in R Studio established the pre-test's internal consistency. The α-value of 0.80 suggests that the instrument's internal consistency is robust (Taber, 2018). The following details the questionnaire results and focus-group interviews conducted during the research period to answer the second research question regarding the students' perceptions of Didax VAT.

Figure 6 shows the overall results of the 10 Likert-scale items. Results from Items 1, 2, 4, and 5 elucidate students' general perceptions about the intervention lessons. More than 50% of the participants disagree with the statement Item 1, "I have difficulty understanding the topic", which indicates that the intervention lessons were effective in helping them understand the topic. This statement is affirmed by 63% of the participants agreeing to Item 2, "I can solve most of the questions easily". Most participants (66%) agreed that they had gained new knowledge during the intervention lessons, with 15% strongly agreeing with the statement. Although the bar graph of Item 4 skewed to the more favourable side, 20 out of 41 students remained neutral when asked whether the intervention lessons reinforced their mathematical knowledge or skills. This might indicate that while some students might benefit from the intervention, others might prefer a different strategy to learning algebra. They might be open to learning, but a different strategy or approach should be adopted to elicit a more positive engagement. Nonetheless, a neutral perspective can be seen as a starting point for adjusting the intervention lessons and the way VAT is used in the lessons.

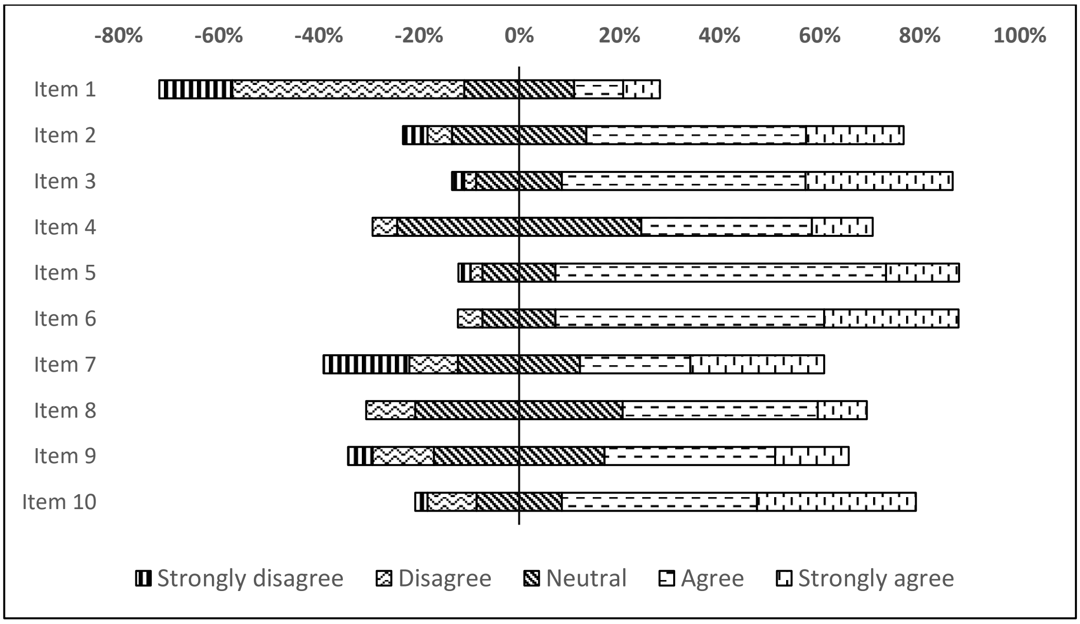

Figure 6. Results of the 10-item Likert-scale Questionnaire

Meanwhile, Items 3, 8, and 9, as shown in Figure 7, show that 78% of the students found Didax VAT helpful in helping them understand how to solve algebraic equations. Moreover, most students responded positively regarding the Didax VAT intervention, and almost 50% said they would use the Didax website for future learning. However, although students find Didax VAT helpful in learning to solve algebraic equations, Item 7 revealed that most students (47%) still prefer to do mathematical tasks on paper rather than online (see Figure 8). In addition, four out of the total number of students choose to use something other than VAT in learning Mathematics, citing various reasons such as Wi-Fi connection problems, difficulty in understanding the concept of algebra tiles and website issues. Despite some issues, the results reveal a positive response to the intervention lessons using Didax VAT. Item 10 indicates that 70% of the students like using the Didax VAT to solve algebraic equations. From the analysis of the Likert-scale questionnaire, the lessons on Didax VAT received favourable responses from the students, evident from the more positively skewed bar graph, with the majority of the students stating that VAT helped them understand how to solve algebraic linear equations and that utilising the Didax website for other virtual manipulatives for learning would be beneficial to the students.

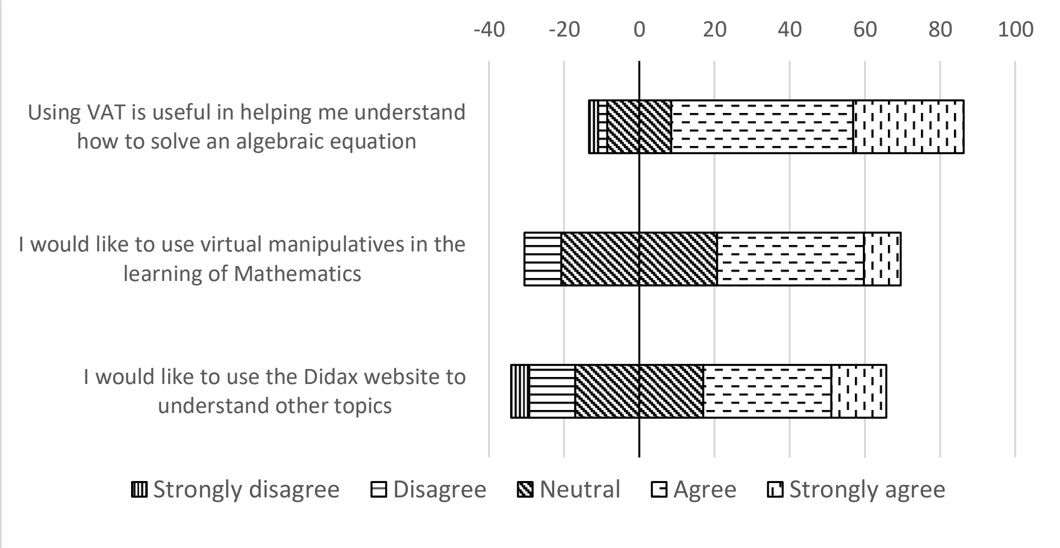

Figure 7. Students' Perception of Didax VAT, Virtual Manipulatives and Didax Website

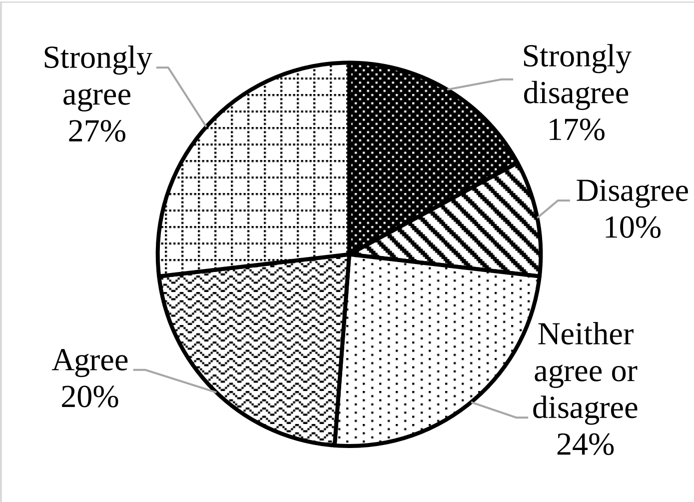

Figure 8. Students' Responses to Item 7

Results of the Focus Group Interviews

The focus-group interviews were conducted with 15 randomly selected participants. The focus-group interviews were conducted in three separate sessions, with five students present during each session. The transcripts for each session were analysed, and three recurring themes were identified: (i) enjoyment of using technology during lessons, (ii) reinforcement of mathematical knowledge, and (iii) difficulties encountered when using Didax VAT.

Theme 1: Enjoyment of Using Technology During Lessons

In all three focus-group sessions, many participants enjoyed using technology during the intervention lessons. When asked about their experiences using Didax VAT, the statements "fun" and "easy" were uttered multiple times and agreed upon by the participants in all the sessions. These highlighted the students' strong positive sentiment towards using technology. The short excerpts are shown below.

Student 8XC:	*Siuk lah jua. Sanang kan buat.* [It's fun and easy.]
Student 8XQ:	*Siuk and sanang dipahami.* [It's fun and easy to understand.]
Student 8XN:	*Ya siuk pasal pakai computer and pakai web.* [It's fun because we use the computer and go on the web (browser).]

In addition, Student 8YF mentioned that "it's not only educational, it's also entertaining", which suggests that the students view the Didax VAT as a form of educational activity in which they can actively engage. Student 8XC affirmed his enjoyment by saying that the Didax VAT is "game-like". The enjoyment during the intervention lesson also comes from the fact that the students use technology in their learning. This is parallel to the statements in the questionnaire, which asked what they thought were the advantages of using Didax VAT in their learning. Some statements include "Using VAT makes Maths more fun" and "It did increase my understanding because it's fun and easy to remember". These statements are seen as positive perceptions of using Didax VAT in students' learning, reinforcing that Didax VAT can actively engage students in learning Mathematical concepts such as solving algebraic equations.

Theme 2: Reinforcement of Mathematical Knowledge

The focus-group interview sessions revealed that the perception of Didax VAT as effective in reinforcing mathematical knowledge of solving algebraic equations was mixed. This finding is parallel to the results from the questionnaire in which almost 50% of the participants remained neutral when asked whether the intervention lessons helped reinforce their knowledge of algebra. On one hand, many students expressed that Didax VAT is "easy" to understand and do. An excerpt from a discussion between the participants and the interviewer regarding Didax VAT is shown below.

Student 8YF:	I like it because I understand the topic better, in my opinion. And like I said before, I like how it's visualised so I can see it.
Student 8YT:	*Banar pulang, macam sanang untuk belaja*r using that *sebabnya ada* some people *payah kan faham*, so *sanang* because *ani* symbolise *ani. Kalau merah, cematu.* [It's true, it's easy to learn using that because some people find it difficult to understand, so it's easy because of the symbols. If it's red, it's this.]
Interviewer:	So, you agree with Student 8YF saying that you can visualise what to do with the symbols.
Student 8YP:	(For) Maths, we only see numbers. But with this, there's more to see. *Kami inda ngalih liat numbers.* [We're not tired because we're not just looking at numbers]. There are colours.

Student 8YF: And it doesn't look as complicated as how you would see numbers. It's not as difficult to look at.

This discussion shows that the students find it easier to understand the topic because of the visual representation of the algebraic equations. As Students 8YF, 8YT, and 8YP mentioned, the tiles' imagery and the associated colours helped them understand the necessary steps to solving algebraic equations. This sentiment was also reflected during the focus-group interviews with the other students, where statements such as "it's easy to remember the tiles", "you can see the diagram", and "you don't need working" were uttered during the discussion.

On the other hand, the intervention lessons could have been more effective for students of high ability as they find it time-consuming and, alternatively, would want to solve the algebraic equation using methods like balancing where the use of algebraic tiles is unnecessary. A fascinating statement by Student 8YM highlighted the need for Didax VAT to be introduced at the beginning of the topic on Algebra as a whole concept instead of during intervention lessons where other methods, such as balancing, have been introduced.

Student 8YM: Algebra tiles *atu patutnya* [it's supposed to be] in the beginning *wah arah* [of] (the) topic algebra but then we learn solving algebra *dulu* [first], solving *nya macam biasa* [like normal] and then *baru* we learn the algebra tiles, so I find it *macam inda* [not] effective because we know the first method *sudah* [already].

Theme 3: Difficulties Encountered When Using Didax VAT

Despite the enjoyment of using technology in their learning, students have highlighted several aspects of Didax VAT that they found needing help with. One of the prevalent issues highlighted was the disruption due to the slow internet access through Wi-Fi, which resulted in more waiting time to load the website during the lesson. Moreover, the Didax website has several glitches, such as some tiles needing to be moved. The sentiments were expressed across all three focus group discussions. Similar conversations about the participants' dislike of using Didax VAT are shown below.

Student 8YP: *Wi-Fi sekolah lagging* so *kami* waste time. [The Wi-Fi connection in school lags so a lot of time is wasted].
Student 8YF: Yeah.
Student 8YF: Or if you're trying to drag it, it won't drag.
Student 8YP: Glitch!
Student 8XN: *Ya kadang-kadang lagging*. [Sometimes, it lags.]
Interviewer: In what sense?
Student 8XN: *Macam inda dapat digerakkan*. [You cannot move it.]

Some focus group participants highlighted a particular difficulty in using Didax VAT. They said the website needed to include keys or labels to identify the different algebraic tiles.

Student 8YF:	I also have one negative thing, which is kind of confusing sometimes because of the blocks. There are not really exact numbers on it, so it’s kind of difficult to remember, and sometimes it’s confusing, so that’s all. But then, it’s still good, in my opinion. It’s good for people who can’t focus well, so it’s entertaining. That’s what someone can focus on.
Student 8YE:	What I don’t like is that it doesn’t show what the diagram was meant for.
Student 8YM:	Mhmm
Student 8YE:	Like what that shape means. Like what the shape represents, it didn’t show. It only showed the diagram.
Student 8YL:	And colours.
Student 8YM:	Colours.
Interviewer:	Alright, okay. So, it would be useful if you had on the side what each of the shape represents rather than just showing the colours and the shape.
Student 8YL:	Yes.
Student 8YE:	Without it, it will be so confusing.

Hence, the participants expressed their difficulties during their experiences of using Didax VAT, mainly due to the slow internet connection, occasional website glitch and the absence of labels for the algebraic tiles.

Overall Synthesis of the Results

Although the paired sample t-test yielded non-significant results, the qualitative data revealed an overall positive perception of using Didax VAT, which affirmed the importance of virtual manipulatives in aiding student learning. Based on the analysis of the questionnaires, more than half of the participants maintained that they gained new knowledge during the intervention and would use the Didax website for future learning. This shows the usefulness of Didax VAT in improving the students’ mathematical understanding of solving algebraic equations and engaging them in further learning other mathematical concepts. These statements are further validated during the focus-group discussions, where the themes revealed that the participants felt a sense of enjoyment in using technology to learn about algebraic equations and that the visual representation of the algebraic equations helped reinforce their mathematical knowledge despite the difficulties encountered by the participants in using the Didax VAT. This affirms that modelling tools such as algebra tiles can aid students in drawing the connection between concrete representation and abstract ideas (Ojose, 2008), making it more understandable for students. This is synonymous with research by Furner and Worrell (2017), who affirmed that mathematics manipulatives help students learn mathematics more engagingly and enjoyably. The findings are also comparable to research by Teck (2013), who asserted that VAT serve as a tool to promote students’ conceptual understanding of algebra.

Finally, it was found that there was no significant correlation between the student's perception of the Didax VAT and the post-test scores. Hence, it can be said that perception has no significant impact in increasing students' achievement levels and that the increase in post-test scores is possibly attributed to the intervention lessons themselves, which strengthened their conceptual understanding in solving algebraic equations but are not necessarily linked to their attitudes towards the usage of Didax VAT. This finding is consistent with Lee et al.'s (2011) research, which found that the perception of students' support was not directly linked with their final marks. In contrast, research by Ahmed et al. (2018) has shown a significant positive correlation between students' perception of the learning environment and their academic achievements. However, it is worth noting that research focusing on the relationship between students' perception of virtual manipulatives and post-test scores remains sparse and needs further investigation to determine the relationship's strength.

There are several limitations to this research. Firstly, conducting a pilot study before the research would be beneficial. This will be useful as it enables the researcher to test the approach's feasibility by reviewing the preliminary results, thereby re-evaluating the epistemological and methodological decisions (Secomb & Smith, 2011). However, a pilot study could not be performed due to time constraints. Secondly, due to the unpredictable COVID-19 endemic situation (at the time of this study), teaching and learning can shift from physical to online at any time, resulting in shifts in timeline and variations in data collection.

Conclusion

This study revealed some prominent findings regarding the effects of Didax VAT on students' performance and their perception of using Didax VAT in solving algebraic linear equations. Most students had an overall positive perception of the Didax VAT when learning to solve algebraic linear equations. It engaged them in learning and solidified their mathematical knowledge despite issues faced with the Didax website and internet connection. However, some students expressed discontent over the absence of labels for each algebraic tile, making it difficult to discern which to use to solve the equation. It is also recommended that the Didax VAT provided should be labelled accordingly to avoid confusion.

These results hold implications for transforming pedagogy for teaching, specifically in mathematics education. It has been shown that Didax VAT can help teachers enhance students' understanding of abstract concepts, such as solving algebraic equations. However, it is highly recommended that Didax VAT be introduced during the first Algebra topic. The second important implication of the study is that the positive student perception of using Didax VAT during lessons can prompt teachers to use Didax VAT in their teaching to facilitate student learning and, thus, can be used as one of the strategies for student engagement. The results have affirmed that the benefits of using Didax VAT far outweigh the drawbacks and effectively show that technology can be used in a classroom setting. This is a crucial implication for developing technology skills further, one of the pivotal components in 21st-century skills. Thirdly, an emerging area of interest that can be further explored is the study of other Didax virtual manipulatives, such as colour counters, base ten blocks, fraction tiles and number lines, and their potential impact on the teaching and learning of Mathematics. Given the lack of research on virtual manipulatives, Didax virtual manipulatives and their effects on pedagogy, student achievement, learning, and 21st-century skills could be studied.

There are several recommendations for future researchers wishing to replicate the study. Firstly, it is recommended that the intervention lessons be lengthened to more than three lessons to ensure students have a proper grasp of the concepts learned during the period and that the lesson plans of the intervention be adjusted according to the student's pace. Secondly, a delayed post-test can be performed to investigate further the retention of knowledge of the concepts learned during the intervention. Commonly administered two or more weeks after the post-test, a delayed post-test can reveal further insights into the effects of VAT. Finally, the findings of this study revealed that the perceptions of using VAT were predominantly positive. Hence, it is worth investigating the significance and strength of the relationship between perceptions of using VAT and students' academic achievements so the gaps in the research may be further addressed.

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Appendix A

Pre-test and Post-test Marking Scheme and Rationale for Inclusion of Questions

No.	Question	Marks	Rationale	No.	Question	Marks	Rationale
1.	$x + 1 = 3$ Ans: $x = 2$	1	• One-step problem • Positive coefficient • Positive constants • Operation: Addition/subtraction	6.	$3x + 5 = 11$ Ans: $x = 3$	2	• Two-step problem • Positive coefficient • Includes positive constants • Operation: Addition/Subtraction Multiplication/Division
2.	$x - 2 = 5$ Ans: $x = 7$	1	• One-step problem • Positive coefficient • Includes negative constants • Operation: Addition/Subtraction	7.	$-6x - 2 = 16$ Ans: $x = -3$	2	• Two-step problem • Negative coefficient • Includes positive and negative constants • Operation: Addition/Subtraction Multiplication/Division
3.	$4x = 16$ Ans: $x = 4$	2	• One-step problem • Positive coefficient • Operation: Multiplication/Division	8.	$5x + 10 = -15$ Ans: $x = -5$	2	• Two-step problem • Positive coefficient • Includes positive and negative constants • Operation: Addition/Subtraction Multiplication/Division
4.	$\frac{x}{3} = -7$ Ans: $x = -21$	1	• One-step problem • Positive coefficient • Includes negative constants • Operation: Multiplication/Division	9.	$7x - 3 = -24$ Ans: $x = -3$	2	• Two-step problem • Positive coefficient • Includes negative constants • Operation: Addition/Subtraction Multiplication/Division
5.	$2x - 3 = 5$ Ans: $x = 4$	1	• Two-step problem • Positive coefficient • Includes negative constants • Operation: Addition/Subtraction Multiplication/Division	10.	$-3x - 5 = 19$ An: $x = -8$	2	• Two-step problem • Negative coefficient • Includes negative constants • Operation: Addition/Subtraction Multiplication/Division

Appendix B

Questionnaire

Please answer the following questions about the intervention lessons using Didax Virtual Algebra Tiles (VAT).

A. Please tick (✓) in the box provided.

No.	Question	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree
1.	I have difficulty understanding the topic.					
2.	I can solve most of the questions easily.					
3.	Using Didax VAT is useful in helping me understand how to solve an algebraic equation.					
4.	My mathematical knowledge/skills were reinforced by doing the intervention lessons.					
5.	I gain some new knowledge during the intervention lessons.					
6.	The Didax VAT is useful in helping me learn mathematics.					
7.	I prefer doing mathematical tasks on paper compared to doing it online.					
8.	I would like to use virtual manipulatives in the learning of mathematics.					
9.	I would like to use the Didax website (IT system) to understand other topics.					
10.	Overall, I like using Didax VAT to solve algebraic equations.					

B. In your opinion, what are the advantages of using Didax VAT? Please explain.

____

C. In your opinion, what are the disadvantages of using the Didax VAT? Please explain.

____

D. In your opinion, did the intervention lessons help increase your understanding of solving algebraic equations? Please explain.

____

Appendix C

Focus Group Interview Questions

- Describe your experience using the Didax VAT during the intervention lessons.
- Have you had other experiences of using a digital learning tool with other subjects?
- What do you like about the Didax VAT?
- What do you dislike about the Didax VAT?
- Do you think the Didax VAT is an effective tool for students to use to learn how to solve algebraic equations?
- Explain your answer.
- Does anyone agree or disagree?
- Given the chance, would you use virtual manipulatives such as Didax VAT to help you understand the topics learned?
- Explain your answer.
- Does anyone agree or disagree?