Jurnal Elemen, 10(1), 28-42, January 2024
https://doi.org/10.29408/jel.v10i1.19786

e- ISSN: 2442 - 4226

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Enhancement of students' mathematical connection through Knisley mathematics learning model assisted by GeoGebra

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Abstract

This study aims to determine whether the increase in the mathematical connections of students who receive the Knisley mathematics learning model is higher than students who receive conventional learning models. The method used in this study was a quasi-experimental design with a nonequivalent control group. This study involved two classes: an experimental class and a control class. Students in the experimental class learned with the Knisley mathematics learning model assisted by GeoGebra, while students in the control class received learning with conventional learning models. This research involved 50 students in class. The study was conducted with the object of this research, which is the ninth grader students in one of the public junior high schools in Bandung. The results showed that the increase in the mathematical connections of students who received the Knisley mathematics learning model was more elevated than that of students who received conventional learning. Knisley's mathematics learning model provides space for students to build their knowledge and can facilitate students in fulfilling mathematical connection indicators. Learning using GeoGebra can increase student enthusiasm. Student activeness in learning can be increased by applying the GeoGebra-assisted Knisley mathematics learning model.

Keywords: GeoGebra; Knisley's mathematics learning model; mathematical connections

How to cite: Ichtiari, A. R., Fisher, D., Rahman, T., & Yatim, S. A. M. (2024). Enhancement of students' mathematical connection through knisley mathematics learning model assisted by GeoGebra. *Jurnal Elemen*, *10*(1), 28-42. https://doi.org/10.29408/jel.v10i1.19786

Received: 3 July 2023 | Revised: 13 September 2023
Accepted: 2 February 2024 | Published: 8 February 2024

Introduction

Mathematical abilities include hard and soft skills that will be achieved in learning (Apriatni et al., 2022). Hendriana et al. (2021) state that students' hard mathematical skills are not only rote but require students' thinking abilities so that meaningful knowledge and a higher level of mathematical thinking will be obtained in mathematics. According to Darwanto (2019) and Sumarmo (2014b), mastering mathematics for cognitive aspects only requires hard mathematical skills. Sumarmo (2014a, 2014b) mentions various mathematical hard skills, including understanding, problem-solving, communication, representation, connection, and mathematical reasoning.

One of the hard skills that students must master is mathematical connections. According to NCTM (2000), an essential connection for the early development of mathematics is the connection between mathematics obtained from student experience and mathematics obtained from learning in schools. These connections include connections between mathematical concepts, between mathematical topics, between mathematics and other fields of study, and between mathematics and daily life. According to Monroe and Mikovch (1994), there are at least three kinds of valuable connections: connections in mathematics, between curricula, and connections with real-world contexts. These two opinions explain that the connection in question is not only in the context of mathematics but the connection between mathematics and contexts outside of mathematics, such as other fields of science and daily life.

Maulida et al. (2022) stated that students will have a broad picture of mathematics when they can relate concepts, facts, and procedures in mathematics. The importance of mathematical connections is also reinforced by the opinion of NCTM (2000) that if students need better mathematical connections, they must learn and remember too many concepts and procedures in mathematics. Conversely, having good mathematical connections allows students to build a new understanding based on previously known understanding. Therefore, it is essential to instill students with mathematical connections because by having mathematical connections, students will have broad insight.

Not all students have optimal mathematical connections. It can be seen from the results of research conducted by Andriani and Aripin (2019) showing that the mathematical connection of 37 class IX students on the indicator of understanding the relationship between mathematical topics, only 37.84% of students were able to answer correctly. On the indicator of seeking equivalent representation of the same concepts and procedures, only 32.44% of students were able to answer correctly. As well as on indicators of using mathematics in other fields of study or daily life, only 16.22% of students were able to answer correctly. Based on the results of this study, the most errors students make on indicators are using mathematics in other fields of study or daily life.

The success of mathematical connections can be influenced by several factors, one of which is how the teacher delivers the material. In addition, students' activities in the classroom also need to be considered because the principle of learning is learning by doing. So that the learning process in the classroom must prioritize student activity so that learning is optimal and effective. Students need to participate actively in reflecting on what they learn to maintain their cognitive development in a social environment (Fisher et al., 2020). One way to increase student activity in learning is to apply the suitable learning model. This learning model must provide opportunities for students to relate concepts in mathematics to optimize the success of students' mathematical connections.

One learning model that has the potential to generate student activity in learning and associating mathematical concepts is the learning model developed by Jeff Knisley (2003). Knisley's mathematics learning model was created based on Kolb's learning theory, which is interpreted into four stages of learning. These stages include allegorization, integration, analysis, and synthesis. Through learning with the Knisley mathematics learning model, students can learn the interrelationships between mathematical concepts and the use of mathematical concepts in problems in other fields of study and everyday life.

Mulyana (2009) mentions several advantages of the Knisley mathematics learning model. Each stage of the Knisley mathematics learning model changes the level of activity between the teacher and students so that the learning process is not only centered on the teacher, but students also play an active role, and there is interaction between students and between students and teachers. In addition, each stage in the Knisley mathematics learning model can trigger the activity of all parts of the student's brain to make learning more effective. Khairani and Putra (2020) state that Knisley's mathematics learning model allows students to explore various questions, ideas, opinions, and statements. Deddy et al. (2012) said that Knisley's mathematics learning model adheres to a learning paradigm that includes exploration, elaboration, and confirmation activities.

Koehler and Mishra (2009) state that Technological Pedagogical Content Knowledge (TPACK) is a form of knowledge that includes three core components: content, pedagogy, and technology. TPACK is a form of knowledge that emerges from the interactions among the three. The application of TPACK in learning, especially mathematics, is using software that can be used to solve mathematical problems and to create virtual learning media, one of which is GeoGebra. According to Hohenwarter et al. (2008), GeoGebra is open-source software or software that can be used in general without charge. The basic idea of this software is to combine algebra, geometry, and calculus in one package that can be used in learning mathematics from elementary school to university.

Based on these problems, research needs to be carried out to improve competence and support the skills possessed by students. Nurhidayah & Susanti (2019) conducted research with the title related to the Influence of the Knisley Learning Model on the Mathematical Connection Ability of Class VIII Students at SMP Negeri 7 Merangin. Agistnie et al. (2022) conducted research with the title Kolb-Knisley Learning Model Assisted by Geogebra on Students' Reasoning Ability in Solving PISA Equivalent Questions, and Fauzy et al. (2023) conducted research with the title Learning Materials for Building Flat-Side Spaces Using Models Knisley Mathematics and Geometry Applications. Previously, research similar to this research had never been carried out. This research aims to determine the increase in junior high school students' mathematical connection abilities using the Knisley model and with the help of dynamic Geogebra software.

This study aims to determine whether the increase in the mathematical connections of students who received the Knisley mathematics learning model assisted by GeoGebra was higher than that of students who received conventional learning models.

Methods

This research examines the effect of the Knisley learning model treatment assisted by Geogebra software on one class with students' mathematical connection abilities. Thus, this research is experimental. According to Campbell and Stanley (1963), this design is one of the educational research designs involving two groups, namely the experimental group and the control group, which is formed naturally like a classroom. So, this study involved two classes, which became the experimental class and the control class. The experimental class received learning treatment with the Knisley mathematics learning model assisted by GeoGebra, while the control class received learning treatment with conventional learning models.

The population in this study was class XI SMA Darul Hikam Bandung, taking samples using a purposive sampling technique, namely selecting samples based on the researchers' considerations regarding the most valuable and representative samples (Babbie, 2021), so that classes XI IPA 1 and XI IPA 2 were obtained as experimental classes and the control class with the consideration that both classes have the same abilities.

This study uses a mathematical connection test instrument for the pretest and posttest in the form of a description of 4 items according to the mathematical connection indicators according to Sumarmo (2014a, 2014b), namely: (1) looking for relationships between various representations of mathematical concepts and procedures; (2) looking for the relationship of one procedure to another in an equivalent representation; (3) applying the relationship between mathematics topics and topics in other fields of study; and (4) using mathematics in other fields of study or everyday life.

The data analysis used is descriptive statistics and inferential statistics. Descriptive statistics are used to find out the general description of students' mathematical connections. The inferential statistics used in this study is the t-test using the Independent Sample t-test with normality tests and homogeneity tests as prerequisite tests. Data analysis on improving students' mathematical connections used the N-Gain index formula proposed by Hake (1999) and its interpretation. The tool for processing data is SPSS Statistics 17.0.

Results

The pretest results showed that the average difference between the two classes was 0.16, so it was suspected that the initial abilities of the students in the two classes were similar. After testing the similarity of the two means using the Independent Sample t-test, it was found that the initial ability information was not significantly different. After the two classes received treatment for four meetings by providing two other learning models, the N-Gain test was carried out for the pretest and posttest results. The following is the analysis of increasing students' mathematical connections.

The data analysis used to determine the increase in students' mathematical connection ability is the N-Gain index formula proposed by Hake and its interpretation. The calculation results show that the average N-Gain score for the experimental class is 0.657, and for the control class is 0.296. According to the interpretation of the calculation of the N-Gain index according to Hake (1999), the experimental class experienced an increase in moderate quality, and the control class experienced an increase in low quality. The interpretation of the N-Gain scores of the experimental and control classes regarding students' mathematical connection abilities can be seen in Table 1 below.

Table 1. Interpretation of student N-Gain scores

Indeks *Gain* (g)	**Number of Students in the Experimental Class**	**Number of Students in the Control Class**
$g > 0.70$	10	0
$0.30 < g \leq 0.70$	15	12
$g \leq 0.30$	0	13

Descriptive statistics for the N-Gain score can be seen in Table 2 below.

Table 2. The average score and standard deviation of the N-Gain score

Indicators	**Mean**	**SD**
N-Gain Experimental Class	0.6578	0.20957
N-Gain Control Class	0.2966	0.09287

Based on Table 2, information was obtained that the difference in the average score of ¬N-Gain in the experimental class and the control class was 0.3612, so it was suspected that the increase in students' mathematical connections in the two classes was significantly different. The standard deviation of the two classes is smaller than the average for each class, indicating that the data is less varied or homogeneous for the experimental and control classes. To determine the validity of increasing students' mathematical connections in both classes, a two-mean difference test was carried out by carrying out a normality test and a two-variance homogeneity test as a prerequisite test. The normality test uses the Shapiro-Wilk statistical test with a significance level of 5%, the results of which are presented in Table 3 below.

Table 3. N-Gain score normality test

	Class	**Shapiro-Wilk**		
		Statistics	**df**	**Sig.**
N-Gain	Experimental	0.932	25	0.099
	Control	0.965	25	0.530

Table 3 shows that the significance value is more significant than 0.05, meaning that the data for both classes are normally distributed. Because the data is normally distributed, a two-variance homogeneity test is then carried out using Levene's test with a significance level of 5%, the results of which can be seen in Table 4 below.

Table 4. Homogeneity test of two variances of N-Gain score

Levene Statistic	**df1**	**df2**	**Sig.**
19.860	1	48	0.000

Table 4 shows that the significance value is less than 0.05, meaning that the posttest data of the two classes are not homogeneous. Because the data were normally distributed and not homogeneous, a two-mean difference test was then performed using the one-party Independent Sample t-test.

Table 5. Test the difference of two mean N-Gain scores

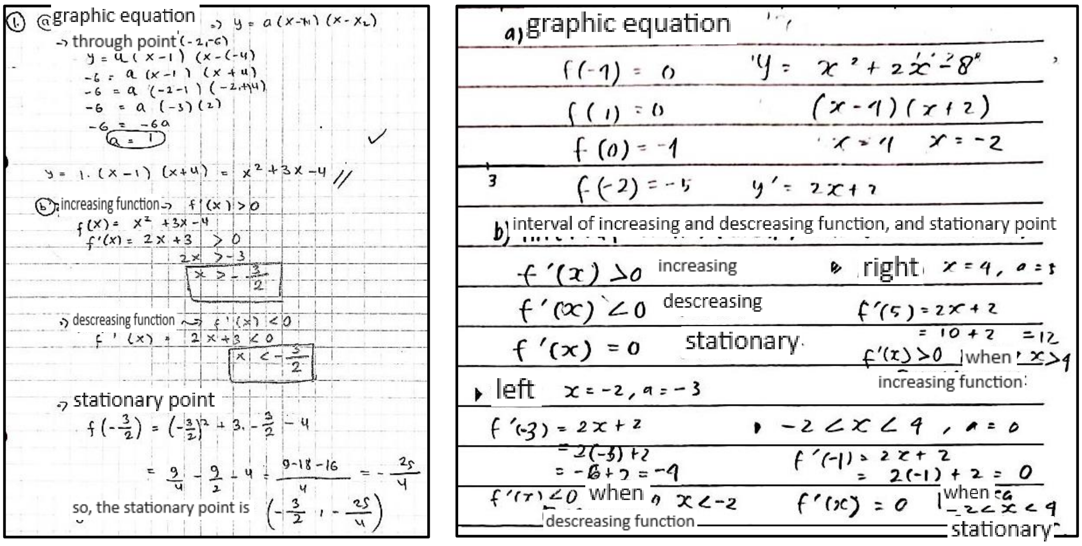
		t-test for Equality of Means						
							95% Confidence Interval of the Difference	
		t	**Df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**Lower**	**Upper**
N-Gain	Equal variances not assumed	7.879	33.77	0.000	0.36123	0.04584	0.26796	0.45449

Based on Table 5, the significance value in the sig. (2-tailed) line equal variances not assumed is 0.000. Because what is being carried out is a one-sided test, the significance value must be divided by two or 0.000/2 = 0.000. The significance value is less than 0.05, and it can be concluded that the increase in the mathematical connections of students who received the Knisley mathematics learning model assisted by GeoGebra was higher than that of students who received conventional learning.

Discussion

The increase in mathematical connection abilities of students who received Knisley mathematics learning assisted by Geogebra software was better than that of students who studied with conventional learning. It proves that compared to traditional learning, mathematics learning using the Knisley model assisted by Geogebra can better facilitate students in training and developing their mathematical connection abilities. It is because, in the Knisley model of mathematics learning, students must be actively involved in studying and discovering for themselves the mathematical concepts being studied through situations or problems presented in the worksheet. As Brunner (Hudojo, 1998) suggested, students learn with active involvement in learning concepts and principles in solving problems. In this case, the teacher, as a learning facilitator, helps students build student knowledge that may be discovered through solving mathematical problems and confirmed by research results Yaniawati et al., (2023) if Mobile-based digital learning materials for the application of the concept of sequences and series of numbers have categories that are suitable for use.

Indicator 1, which is looking for relationships between various representations of mathematical concepts and procedures, has questions consisting of two sub-tasks, namely points a and b. For the question on point a, students are asked to form a quadratic equation from the information provided, which is a quadratic graphic image. In point b, students are asked to determine the intervals where the function increases, decreases, and its stationary point. An example of the results of the answers to indicator question 1 for students in the experimental class and control class can be seen in Figure 1 below.

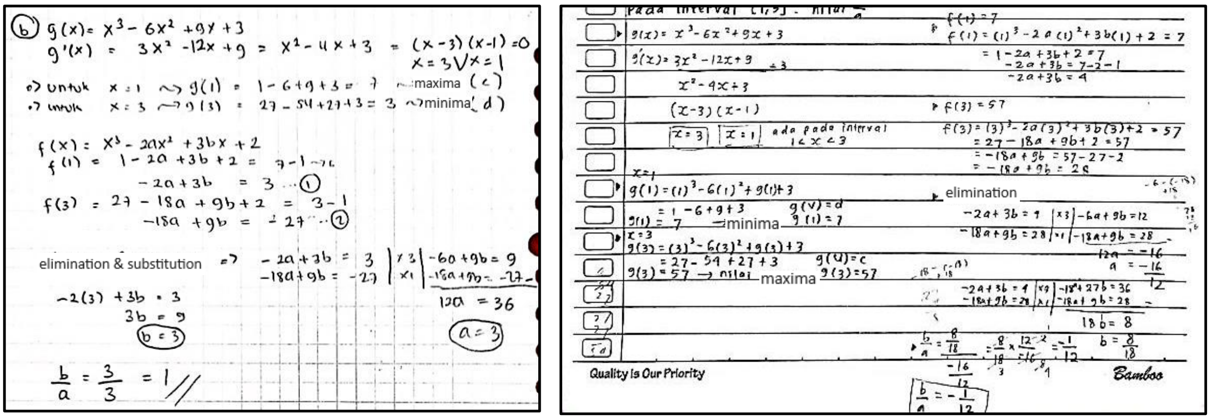


(a) (b)

Figure 1. (a) Experimental class student answers; (b) Control class student answers

Based on Figure 1, the experimental class students in solving point (a) correctly apply the formula to form a quadratic equation if two intersection points are known and one point passes, so the experimental class students solve point (a) correctly. For point (b), the experimental class students were correct in applying the first derivative of the function to determine the increasing and decreasing intervals of the function. They were correct in substituting x values to find stationary values and points. Thus, the answers of the experimental class students were appropriate, and the researcher prepared the alternative answers. Control class students in solving point (a) questions were not correct because students were still wrong in compiling quadratic equations.

For point (b), control class students in determining the intervals of increasing and decreasing functions have implemented derivative applications but still need to be more accurate and efficient. Control class students still need to select the stationary point as requested in the problem. Thus, the answers of the control class students still needed to be corrected and match the alternative answers prepared by the researcher. Based on this description, Knisley's mathematics learning model, assisted by GeoGebra, can help students find relationships between various representations of mathematical concepts and procedures. Indicator 2 looks for the relationship of one procedure to another in an equivalent representation of a problem containing two functional equations to the cube number and their maximum and minimum values in closed intervals. One of these equations is incomplete, students are asked to determine the value of $\frac{b}{a}$. In solving this problem, students are expected to be able to use the method of elimination and substitution. An example of the results of the answers to indicator questions 2 for students in the experimental class and control class can be seen in Figure 2 below.



(a) (b)

Figure 2. (a) Experimental class student answers; (b) Control class student answers

Based on Figure 2, experimental class students solving these problems have applied derivative applications to determine the maximum and minimum values in closed intervals. Students have also been able to identify the information given in the problem and link it to the information obtained from the calculations. Students have applied the elimination and substitution methods to find the variables. Thus, the answers of the experimental class students were appropriate, and the researcher prepared the alternative answers. Control class students solve these problems and have the same solution as students in the experimental class. However, there is a slight error that causes the final answer to be wrong as well. Calculation errors occur when students determine the maximum value of the function g(x), so it needs to be corrected when determining the maximum value of the function f(x). For the rest, the procedure for the answers of the control class students was according to the researchers' expectations. Thus, the answers of the control class students needed to be more fitting and match the alternative answers prepared by the researcher. Based on this description, Knisley's mathematics learning model, assisted by GeoGebra, can help students find relationships from one procedure to another in an equivalent representation.

Indicator 3, namely applying the relationship between the topic of mathematics and the topic of other fields of study, has the form of a question that contains a case related to economics. Students are given the equation of product production price and product selling price. Students are asked to determine each unit's selling price and the company's maximum profit. An example of the results of the answers to indicator question 3 for students in the experimental class and control class can be seen in Figure 3 and Figure 4 below.

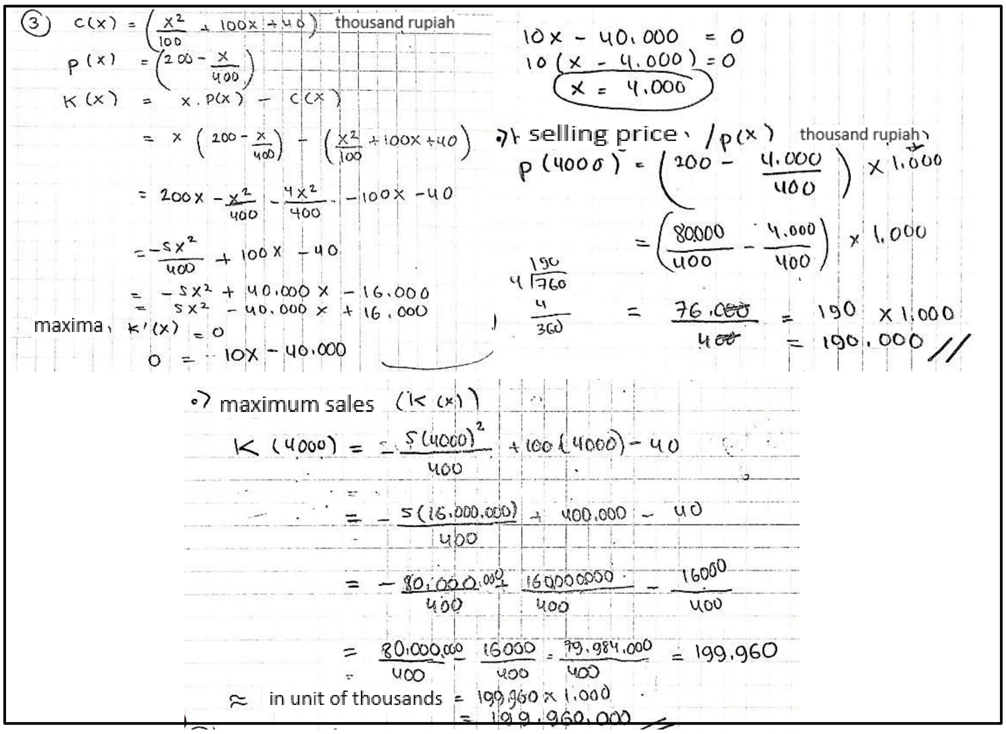


Figure 3. Experimental class student answers

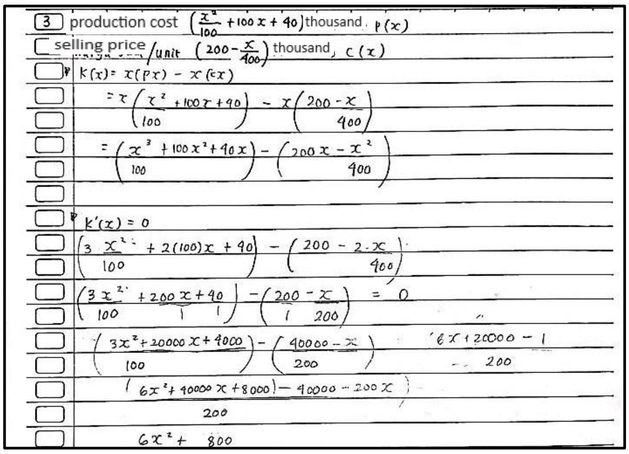
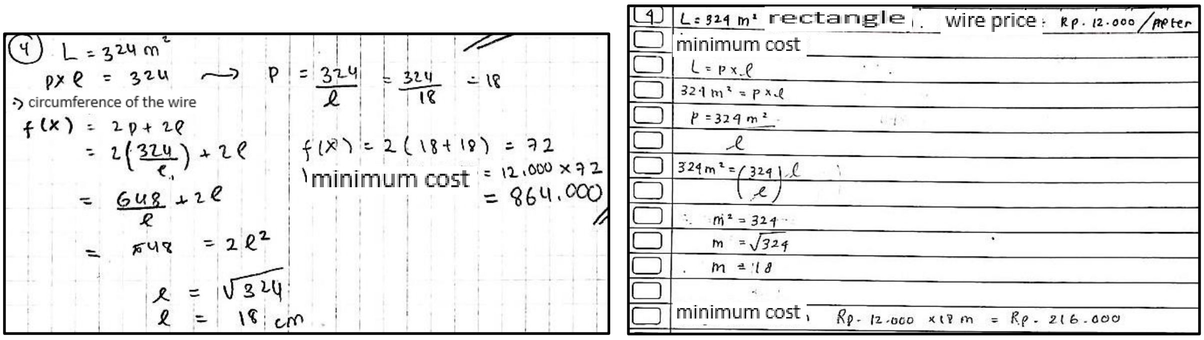


Figure 4. Control class student answers

Based on Figure 3, students in the experimental class could identify the information provided. Forming a mathematical model for profit is also appropriate. Students have used the first derivative to find maximum profit. Students can solve the case thoroughly. Thus, the answers of the experimental class students were appropriate, and the researcher prepared the alternative answers. The illustration in Figure 4 shows that the control class students could identify the information provided in solving these questions. However, students still need to learn to form mathematical models for profit. Students have applied the function's first derivative to find the maximum profit, but the calculations must be completed. It can be seen that students need to be able to solve the case thoroughly. Thus, the answers of the control class students needed to be corrected to match the alternative answers prepared by the researcher. Based on this description, Knisley's mathematics learning model, assisted by GeoGebra, can help students apply relationships between mathematics topics and other subject topics.

Indicator 4, using mathematics in other fields of study or daily life, has questions that contain a case related to problems in everyday life. Students are given a case regarding the area of the farm that will be wired, and students are asked to determine the minimum cost that must be incurred. An example of the results of the answers to indicator questions from four students in the experimental class and control class can be seen in Figure 5 below.



(a) (b)

Figure 5. (a) Experimental class student answers; (b) Control class student answers

Based on Figure 5, experimental class students, in solving these problems, were able to identify the information contained in the problem. Students can form a mathematical model for the perimeter of a rectangle precisely so that they can solve it to determine the minimum cost. It can be seen that students were able to solve the case thoroughly. Thus, the answers of the experimental class students were appropriate, and the researchers prepared the alternative answers. In solving these problems, control class students have been able to identify the information contained in the problem. However, the students did not form a mathematical model for the perimeter of the rectangle, as the researchers expected. Hence, the students needed to be corrected in determining the minimum cost. Thus, the answers of the control class students needed to be corrected to match the alternative answers prepared by the researcher. Based on this description, GeoGebra-assisted MPMK can help students use mathematics in other fields of study or daily life.

Based on the findings in the field, students in the experimental class are required to be active in building and developing new concepts based on various concepts they previously knew and to understand new concepts visually using GeoGebra software so that students can apply new concepts in solving various problems related to other fields of study and daily life. It is in line with the opinion of Trisnawati (2015) that Knisley's mathematics learning model supports students to be more active in learning because students are invited to formulate new concepts so they can solve problems with the concepts that have been formed. Nurhidayah and Susanti (2019) also stated that applying the Knisley mathematics learning model in learning can train students' mathematical connection abilities because, in the learning process, students are invited to recall the concepts they have learned. Thus, students can recall the concepts learned with their abilities.

Applying the Knisley mathematics learning model in learning can also increase student activity in the learning process. It aligns with the analysis stage, where students want to get information and the teacher as a source. It increased student activity, especially in asking questions (Anaguna & Suhendra, 2019; Rodiawati, 2016). Thus fostering active interaction that occurs in two directions between teachers and students.

Each Knisley mathematics learning model stage can help students fulfill the mathematical connection indicators. At the allegorization stage, students formulate new concepts in concepts they already know before. According to Crawford et al. (2005), this stage focuses students' attention at the beginning of learning by recalling knowledge students already have and providing context to make it easier for students to understand new ideas. In other words, students are expected to be able to recognize equivalent representations of similar concepts.

In the integration stage, students discuss using Student Worksheets in groups to distinguish new concepts from previously known concepts through comparison, measurement, and exploration. According to Septiani and Andiani (2021), students complete the steps in the Student Worksheets by simply applying new concepts. It is intended to explore the properties of the new concept. In other words, students try various procedures that they know before, so it is expected that students can recognize the relationship between a mathematical procedure from a representation to an equivalent representation procedure.

According to Jatiariska et al. (2020), Knisley's mathematics learning model can help students understand concepts by associating new concepts with concepts they have learned before. It is in line with Ausubel's theory of meaningful learning. According to Ausubel's theory, meaningful learning means that students can associate the concepts being studied with concepts they already know. Ausubel's theory is used in the analysis stage of the Knisley mathematics learning model. At this stage, students connect new concepts with known concepts but still need more information about these concepts, so students are required to make or choose questions related to new concepts. Students use this opportunity to ask questions and assess the interrelationships of new concepts with other fields of study. In other words, students are expected to be able to use and assess the interrelationships between mathematical topics and interrelationships outside of mathematics.

At the synthesis stage, students again discuss using worksheets to develop new concepts they have mastered to solve various problems. According to Crawford et al. (2005), at the end of learning, when students understand a new concept, the last thing to do is to reflect on the application of the new concept by testing the new concept and making personal responses. So at t, at his stage, students are expected to be able to use these concepts both in mathematics itself and outside mathematics. In other words, students are expected to be able to use mathematics in everyday life. At this stage, students also make strategies and allegories to solve problems. If students have mastered a mathematical concept, then regardless of the form of the problem given, students will be able to solve the problem with a different solving strategy or not be stuck with the formula given by the teacher (Rahman, 2020)

Learning using GeoGebra provides a fun learning experience for students. It increases students' enthusiasm for learning because they can explore various kinds of concepts related to the studied concepts. In line with the statement of Rismawati et al. (2020), enthusiasm for learning to use GeoGebra is higher because students try various features provided by GeoGebra to construct their knowledge. Using GeoGebra in learning provides a stimulus for students to ask questions, so it helps students build their knowledge. It is in line with the results of Islamic and Setiawan's research (2020) that GeoGebra can foster enthusiasm for asking questions during the learning process. Septian (2022) states that using GeoGebra in learning can positively influence motivation, learning activities, independent learning, and social interaction.

Knisley's mathematics learning model, assisted by GeoGebra, can direct students to learn by recognizing new concepts from previously known concepts, mastering them, and applying them in solving problems. Knisley's mathematics learning model, assisted by GeoGebra, can trigger student activity and enthusiasm in the learning process. It is in line with the statement of Jatiariska et al. (2020) that Knisley's mathematics learning model facilitates students in building their knowledge by providing opportunities to structure what they will learn, how to learn it, and discover what is learned. GeoGebra, as a medium that utilizes technology, can assist students in investigating and trying to find their understanding of the material being studied so that students are more enthusiastic about learning. Thus, applying the Knisley mathematics learning model assisted by GeoGebra in the learning process in groups can impact students' mathematical connections.

Conclusion

The mathematical connections of students who received the Knisley mathematics learning model assisted by GeoGebra were higher than students who received conventional learning models. Knisley's mathematics learning model provides space for students to construct their understanding and knowledge. Each Knisley mathematics learning model stage can help students fulfill the mathematical connection indicators. Using GeoGebra provides a fun learning experience for students and increases students' enthusiasm for learning. The Knisley mathematics learning model assisted by GeoGebra can increase student activity, especially when asking questions.

These findings suggest that the Knisley mathematics learning model assisted by GeoGebra develops students' insight or knowledge and the ability to collaborate, literacy and communication, drawing skills using software, and a good attitude in dealing with various problems. This research is limited to the matter of the research object, which only focuses on mathematical connection ability. So, further research is needed to determine how the Knisley mathematics learning model assisted by GeoGebra affects other hard skills.

Acknowledgment

Thank you to the principal of Darul Hikam Senior High School who has permitted for the research, and to all students of class XI IPA 1 and XI IPA 2 who have participated in this research. Thank you to the Faculty of Teacher Training and Education of Pasundan University for supporting the funding of this research.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies, have been completed by the authors.

Funding Statement

The Faculty of Teacher Training and Education of Pasundan University support the funding of this research.

Author Contributions

Dahlia Fisher: Conceptualization, design, analysis, writing, final approval, securing funding; **Atina Rahmah Ichtiari:** Conceptualization, design, analysis, writing, final approval; **Taufik Rahman:** Conceptualization, design, analysis, writing, final approval; **Siti Ainor Mohd Yatim:** Editing, reviewing, and supervision.

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