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Misconception Reduction: 4-Tier Diagnostic Test Based on Education for Sustainable Development & Arduino Tools

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ABSTRACT

Misconceptions in mathematics learning, especially numeracy, are significant problems that need to be addressed immediately to improve the quality of education in Indonesia. This study aims to reduce student misconceptions by developing and implementing a 4-Tier diagnostic test based on Education for Sustainable Development (ESD) supported by Arduino tools in the Problem Based Learning (PBL) learning model. The method used is a mixed method with a population of grade X students and a sample consisting of 30 students in one of the Pasundan Cikalongkulon Senior High Schools selected purposively. The research instruments include a 4-Tier diagnostic test and observation sheets. Data were analyzed qualitatively and quantitatively through the concurrent embedded strategy model and Ploomp research design. The results showed that the 4-Tier diagnostic test was effective in mapping students' conceptual understanding and was able to significantly reduce numeracy misconceptions. The application of the ESD-based PBL model was also proven to improve students' numeracy skills. This study indicates that the integration of diagnostic tests in the curriculum is important to improve the quality of learning and student understanding. The use of Arduino in trigonometry learning increases student motivation and engagement. Thus, this learning model can be a solution to improve students' competence in facing the challenges of globalization and technology in accordance with UNESCO's 2030 Agenda.

Keywords: arduino tools; 4-tier diagnostics; education for sustainable development; misconceptions

INTRODUCTION

The Programme for International Student Assessment (PISA) has revealed a weakness in conceptual abilities in Indonesia, which has not been fully contextualized. This is reflected in the less-than-satisfactory results of the Computer-Based National Assessment (ANBK). Indonesia ranked 72nd out of 78 countries in PISA 2018 (OECD, 2020). Although there was an improvement of 5 positions in PISA 2022, this issue remains a primary focus in educational research. PISA conducts diagnostic tests every three years on 15-year-old students from randomly selected schools in reading, mathematics, and science. The results of these tests provide valuable information for improving the education system, as reflected in the education report cards. The concept of numerical literacy refers to the ability to use basic mathematical symbols and numbers to solve everyday problems and analyze data through tables, graphs, and charts. Indonesia's numeracy skills from 2020 to 2022 remain less than ideal and are in a precarious position, necessitating a preliminary study analysis to understand the foundational knowledge possessed by students (Yasin et al., 2023). Since

2000, Indonesia's numeracy skills have consistently ranked below ideal levels, highlighting the need for a preliminary study analysis to identify the fundamental issues faced by students. A preliminary study at SMA Pasundan Cikalongkulon shows that the numeracy results in the 2023 education report indicate a less-than-ideal score, categorized as moderate at 55.56%. Therefore, methods and solutions are needed to improve PISA scores at the international level and to enhance the education report cards assessed at the national level.

The effectiveness of the Merdeka Curriculum in improving Indonesia's position in PISA 2022, as well as its impact on students' numeracy understanding nationwide (Nisya et al., 2023). Through the Merdeka Curriculum, Indonesia is expected to continue enhancing students' competencies in facing the challenges of globalization and technology. According to Herawati et al. (2021), Problem-Based Learning (PBL) is being utilized as an innovation to deepen students' understanding of contextual problem-solving, particularly in trigonometry lessons involving the use of Arduino.

The expected outcome is the development of a Problem-Based Learning (PBL) model based on Education for Sustainable Development (ESD) that enhances numeracy and reduces students' conceptual misunderstandings. ESD is a transformative education approach that offers a new way of viewing the world, involving the development of systemic, critical, and creative thinking, as well as empowering citizens to make decisions for future development (Maulucci et al., 2023). ESD is an educational innovation that contributes to sustainable education in line with UNESCO's Agenda 2030, preparing a generation that is reflective and contributes positively to sustainable development (Rico et al., 2021). The use of the 4-tier numeracy diagnostic test is expected to map students' conceptual understanding, providing insights into the effectiveness of this instrument in improving numeracy skills in accordance with the Merdeka Curriculum, which includes diagnostic tests to map students' abilities (Fadhilah et al., 2020).

The diagnostic results from 33 students showed that less than 30% of them experienced misconceptions with the 4-tier numeracy diagnostic test. Most students could correctly answer multiple-choice questions but could not provide accurate reasoning (Aqila et al., 2022). These results illustrate the extent to which students understand the 4-tier diagnostic test instrument, which is designed to depict students' understanding and tends to require different approaches for each student. This skill is crucial because mathematics is used to solve everyday problems. Currently, industries are advancing by integrating technology into the learning process. In this study, the learning process was supported by Arduino to measure various aspects of bridges and infrastructure. School education must prepare a workforce capable of critical thinking, collaboration, and problem-solving, in line with the ESD approach that shifts the learning paradigm from traditional methods to more active, problem-based, and technology-driven approaches (Ningsih et al., 2019).

Problem-based learning (PBL) is an effective approach for promoting students' higher-order thinking. In the context of mathematics education, using simple mathematical tools in contextual problem-based learning has proven to be more effective (Herawati et al., 2021). The integration of the Problem-Based Learning (PBL) model with Education for Sustainable Development (ESD) offers a fitting solution (Syakur et al., 2017). Mathematical numeracy literacy, which includes exploration, connection, and reasoning, helps students tackle real-world mathematical problems. By combining PBL with contextual learning

processes based on ESD and utilizing 4-tier numeracy diagnostic test instruments, learning can become more contextual and effective.

Misconceptions in mathematics education, particularly in numeracy, present a significant challenge to improving the quality of education in Indonesia. These misconceptions hinder students' conceptual understanding and affect their academic performance. Efforts to reduce these misconceptions require innovative approaches that are grounded in contexts relevant to the students (Zulfikar et al., 2019). One approach that can be applied is the use of Arduino-based mathematical teaching aids, supported by a Problem-Based Learning (PBL) model rooted in Education for Sustainable Development (ESD). This study focuses on the implementation of contextualization of mathematics learning aids through Arduino supported by ESD-based PBL to reduce student misconceptions, increase the effectiveness of the learning process, and use a 4-Tier diagnostic numeracy test instrument to map students' conceptual understanding categories. It is hoped that this will produce effective solutions to overcome misconceptions and improve the quality of mathematics education in Indonesia.

RESEARCH METHODS

The research method is a mixed method with a concurrent embedded strategy model, namely a design that uses quantitative and qualitative methods together in both data collection and data analysis. The research design used refers to the Plomp design in 1997, including 1) initial investigation (initial investigation) by looking for problems in students' conceptual abilities, 2) design stage (design stage) making instruments, 3) realization/ construction stage (realization/construction) analyzing instruments with various assisted tests, 4) test, evaluation, and revision stages (testing, evaluation, and revision stages) assisted by pre-test and post-test results and analysis of the number of groups, and 5) implementation stage (implementation stage) if this instrument is successful, it can be a reference for making diagnostic test instruments in measuring students' conceptual abilities. The scheme related to the stages in the Plomp research design is shown in Figure 1.

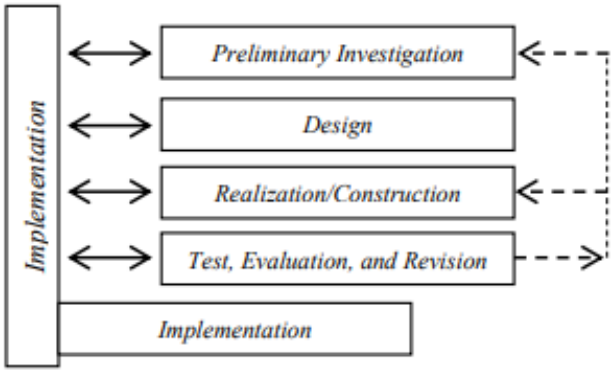


Figure 1. The Plomp Research Design Schematic

The subjects of this study were 30 students of class X at one of SMA Pasundan Cikalongkulon, consisting of 10 males and 20 females who were selected purposively, where students had not studied trigonometric comparisons in class X at the beginning of semester II. The research instruments included a 4-Tier diagnostic test and observation sheets. The

quantitative analysis in this study, namely the n-gain test and the average value of the pretest and posttest, was then strengthened by the relationship between research variables measured using path analysis. Qualitative analysis through direct observation to analyze the results of students' answers in grouping student misconceptions.

RESULTS AND DISCUSSION

Instrument involves several important stages that must be undertaken. Each of these stages is designed to ensure that the instrument is not only accurate but also applicable in real educational contexts. The following are the stages involved in the development of the 4-tier diagnostic numeracy test:

1) Initial investigation

The development of the 4-tier diagnostic numeracy test begins with a preliminary investigation through a literature review. Based on the findings, the numeracy score at SMA Pasundan Cikalongkulon was recorded at 55.56% on the Education Report Card. This result forms the foundation of this research, which aims to improve students' numeracy skills. The score falls within the moderate category, bordering on low, indicating that this instrument has the potential to diagnose students' conceptual levels as an initial investigation.

2) Design

The development of the 4-Tier Diagnostic Numeracy Test involves the following structure: Tier-1 consists of the question itself, Tier-2 assesses the student's confidence level in their answer, Tier-3 requires the student to provide a reason for their answer, and Tier-4 gauges their confidence in the reason given. The diagnostic results categorize or map students into different levels of conceptual understanding, such as fully understanding the concept, partially understanding it, not understanding it at all, or having misconceptions. Numeracy instruments should be introduced to teachers at the elementary school level early on. Once teachers are familiar with and understand these numeracy questions, students will be better able to comprehend and accurately solve them (Sari N.M et al., 2023).

3) Realization/Construction

The researcher developed the questions by modifying the choices in Tier-1 so that they did not include any reasoning. The reasoning was then presented in Tier-3 to accurately assess the responses to questions that probe the reasons for the answers provided in the Tier-1 multiple-choice questions (Zulfikar et al., 2017). This was done to mislead students in providing reasons related to their answers in Tier-1. The 4-tier diagnostic numeracy test was evaluated for its validity, reliability, difficulty level, and discrimination power. The final realization step involved using path analysis to examine the relationship between standardized regression coefficients, which indicate the direct effects of independent variables on dependent variables within the path model. The notation used for path coefficients is $\rho_1 x_1 \; dan \; \rho_2 x_2$ where X and Y are the independent variables and Z is the dependent variable in the research model (Sarwono, 2022). Through this path analysis, the influence of independent variables, namely PBL based on ESD supported by Arduino teaching aids, was found to reduce students' numeracy misconceptions. This realization resulted in the following path analysis test:

Table 1. Path Analysis Result

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.974[a]	.949	.944	1.206

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	sig
	B	Std.Error	Beta		
(Constant)	-1.243	4.827		-.258	.798
PBL (X_1)	.110	.132	.100	.833	.411
ESD (X_2)	-.049	.149	-.039	-.329	.744
Miskonsepsi (y)	.925	.045	.942	20.504	.000

Koefisien Jalur model $Z = \rho_1 x_1 + \rho_2 x_2 + \varepsilon_2$

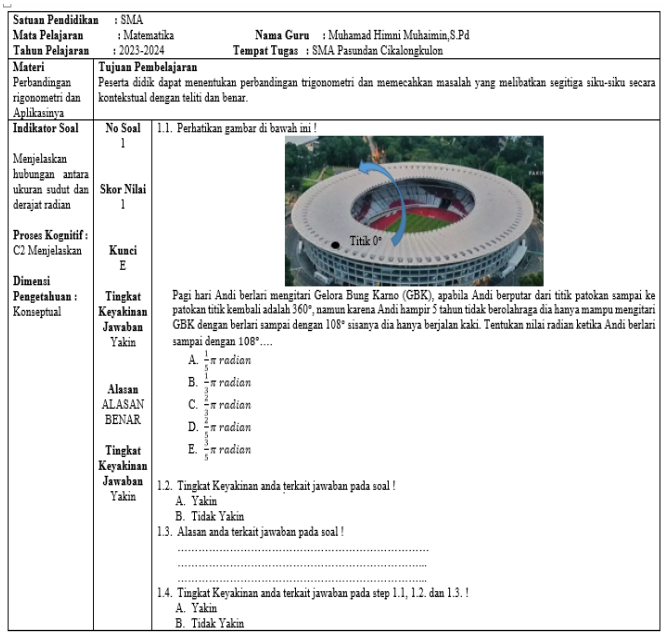
The significance values of the two variables are X_1 = 0,411 , X_2 = 0,744 and Y = 0,00 which are smaller than 0,05 whereas the PBL based on ESD has significance values greater than 0,05 namely 0,411 and 0,744. This result leads to the conclusion that the regression model, with variables X_1, X_2 and Y has a significant impact on Z.

The R square value is 0,949. Indicating that the contribution of X_1, X_2 and Y to Z is 94,9%, while the remaining 5,1% is influenced by other variables not included in the study. To find the value of ε_2 the formula $\varepsilon_1 = \sqrt{1 - 0{,}949} = 0{,}051$ can be used.

4) Test, Evaluate and Revisions

This test is used to assess the students' conceptual understanding to determine if there is a change after being treated with PBL based on ESD, and then compared between the control class and the experimental class.

a) Evaluate. 4-tier diagnostic Numeracy Test



Satuan Pendidikan : SMA
Mata Pelajaran : Matematika **Nama Guru** : Muhamad Himni Muhaimin,S.Pd
Tahun Pelajaran : 2023-2024 **Tempat Tugas** : SMA Pasundan Cikalongkulon

Materi
Perbandingan rigonometri dan Aplikasinya

Tujuan Pembelajaran
Peserta didik dapat menentukan perbandingan trigonometri dan memecahkan masalah yang melibatkan segitiga siku-siku secara kontekstual dengan teliti dan benar.

Indikator Soal
Menjelaskan hubungan antara ukuran sudut dan derajat radian

Proses Kognitif :
C2 Menjelaskan

Dimensi Pengetahuan :
Konseptual

No Soal
1

Skor Nilai
1

Kunci
E

Tingkat Keyakinan Jawaban
Yakin

Alasan
ALASAN BENAR

Tingkat Keyakinan Jawaban
Yakin

1.1. Perhatikan gambar di bawah ini !

Pagi hari Andi berlari mengitari Gelora Bung Karno (GBK), apabila Andi berputar dari titik patokan sampai ke patokan titik kembali adalah 360°, namun karena Andi hampir 5 tahun tidak berolahraga dia hanya mampu mengitari GBK dengan berlari sampai dengan 108° sisanya dia hanya berjalan kaki. Tentukan nilai radian ketika Andi berlari sampai dengan 108°....

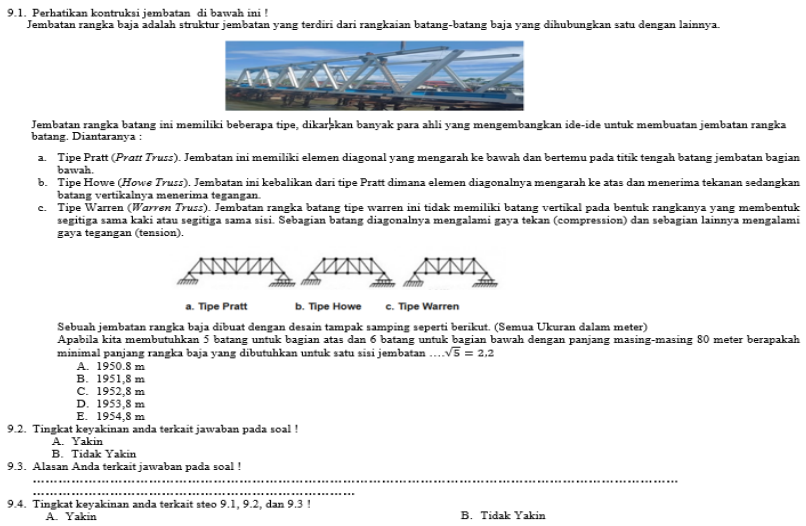
A. $\frac{1}{3}\pi$ *radian*
B. $\frac{1}{4}\pi$ *radian*
C. $\frac{1}{2}\pi$ *radian*
D. $\frac{2}{3}\pi$ *radian*
E. $\frac{1}{5}\pi$ *radian*

1.2. Tingkat Keyakinan anda terkait jawaban pada soal !
A. Yakin
B. Tidak Yakin

1.3. Alasan anda terkait jawaban pada soal !
.....
.....
.....

1.4. Tingkat Keyakinan anda terkait jawaban pada step 1.1, 1.2. dan 1.3. !
A. Yakin
B. Tidak Yakin

Figure 2. 4-Tier Diagnostic Numeracy Test With Question Cards


9.1. Perhatikan kontruksi jembatan di bawah ini !
Jembatan rangka baja adalah struktur jembatan yang terdiri dari rangkaian batang-batang baja yang dihubungkan satu dengan lainnya.

Jembatan rangka batang ini memiliki beberapa tipe, dikarenakan banyak para ahli yang mengembangkan ide-ide untuk membuatan jembatan rangka batang. Diantaranya :

a. Tipe Pratt (*Pratt Truss*). Jembatan ini memiliki elemen diagonal yang mengarah ke bawah dan bertemu pada titik tengah batang jembatan bagian bawah.
b. Tipe Howe (*Howe Truss*). Jembatan ini kebalikan dari tipe Pratt dimana elemen diagonalnya mengarah ke atas dan menerima tekanan sedangkan batang vertikalnya menerima tegangan.
c. Tipe Warren (*Warren Truss*). Jembatan rangka batang tipe warren ini tidak memiliki batang vertikal pada bentuk rangkanya yang membentuk segitiga sama kaki atau segitiga sama sisi. Sebagian batang diagonalnya mengalami gaya tekan (compression) dan sebagian lainnya mengalami gaya tegangan (tension).

a. Tipe Pratt b. Tipe Howe c. Tipe Warren

Sebuah jembatan rangka baja dibuat dengan desain tampak samping seperti berikut. (Semua Ukuran dalam meter)
Apabila kita membutuhkan 5 batang untuk bagian atas dan 6 batang untuk bagian bawah dengan panjang masing-masing 80 meter berapakah minimal panjang rangka baja yang dibutuhkan untuk satu sisi jembatan ....$\sqrt{5} = 2{,}2$

A. 1950,8 m
B. 1951,8 m
C. 1952,8 m
D. 1953,8 m
E. 1954,8 m

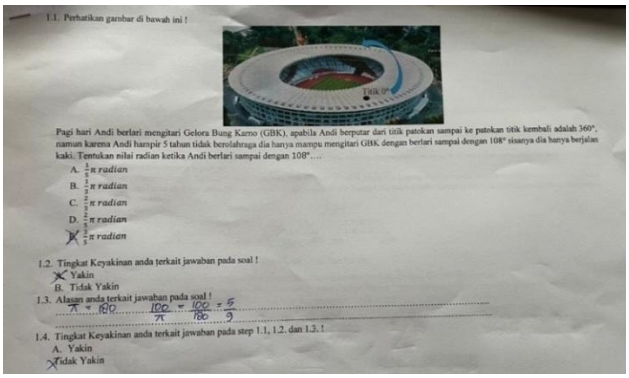
9.2. Tingkat keyakinan anda terkait jawaban pada soal !
A. Yakin
B. Tidak Yakin

9.3. Alasan Anda terkait jawaban pada soal !
.....
.....

9.4. Tingkat keyakinan anda terkait steo 9.1, 9.2, dan 9.3 !
A. Yakin B. Tidak Yakin

Figure 3. 4-Tier Diagnostic Numeracy Test based on Education for Sustainable Development (ESD) without Question Cards

The diagnostic results from 33 students showed that less than 30% of the students had misconceptions with the 4-Tier Diagnostic Numeracy Test. Most were able to correctly answer the multiple-choice questions but could not provide accurate reasoning. The results of the students in answering 2 questions from the 4-Tier Diagnostic Numeracy Test are as follows :


1.1. Perhatikan gambar di bawah ini !

Pagi hari Andi berlari mengitari Gelora Bung Karno (GBK), apabila Andi berputar dari titik patokan sampai ke patokan titik kembali adalah 360°, namun karena Andi harapir 5 tahun tidak berolahraga dia hanya mampu mengitari GBK dengan berlari sampai dengan 108° sisanya dia hanya berjalan kaki. Tentukan nilai radian ketika Andi berlari sampai dengan 108°....

A. $\frac{1}{5}\pi$ *radian*
B. $\frac{1}{3}\pi$ *radian*
C. π *radian*
D. $\frac{1}{2}\pi$ *radian*
X $\frac{3}{5}\pi$ *radian*

1.2. Tingkat Keyakinan anda terkait jawaban pada soal !
X Yakin
B. Tidak Yakin

1.3. Alasan anda terkait jawaban pada soal !
$\frac{x}{360} = \frac{108}{2\pi}$ ... $\frac{108}{360} = \frac{3}{5}$

1.4. Tingkat Keyakinan anda terkait jawaban pada step 1.1, 1.2. dan 1.3. !
A. Yakin
X Tidak Yakin

Figure 4. Results of the 4-Tier Diagnostic Numeracy Test showing students with incomplete conceptual understanding

Based on Figure 4, the results above demonstrate that instruments which only measure students through multiple-choice questions are not sufficient to fully evaluate students. Therefore, a rubric is needed to categorize students, as shown in Table 2 (Zulfikar et al., 2017).

Table 2. Four Test Rubric

Tier-1	*Tier*-2	*Tier*-3	*Tier*-4	Level Konsepsi
1	S	1	S	*Understand* (U)
1	S	1	NS	*Partial Understanding* (PU)
1	NS	1	NS	
1	S	0	S	
1	S	0	NS	
1	NS	0	S	
1	NS	0	NS	
0	S	1	S	
0	S	1	NS	

0	NS	1	S	
0	NS	1	NS	
0	S	0	S	*Misconception* (M)
0	S	0	S	*Not Understanding* (NU)
0	S	0	S	
0	NS	0	S	
0	NS	0	NS	
There are tiers that are either left unanswered or answered with more than one option available.				*Uncode* (UC)

Keterangan
1 = (Correct Answer)
0 = (Incorrect Answer)
S = Sure
NS = Not Sure

The following is an example of an Arduino tool for contextually analyzing the front, side, and hypotenuse distances :

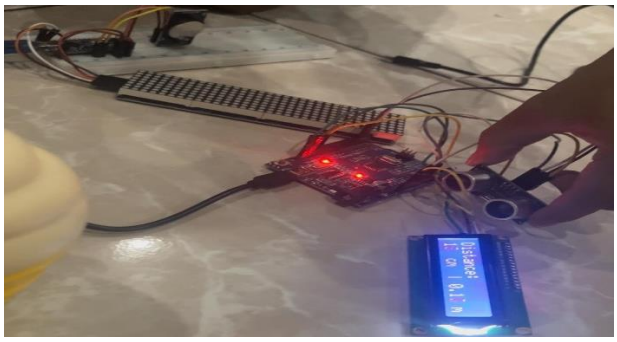


Figure 5. Creation of a Teaching Tool in Mathematics Learning based on Education for Sustainable Development (ESD)

Evaluation is conducted to detect and diagnose students within groups based on different levels of conceptual understanding, such as fully understanding the concept, partial understanding, no understanding at all, or having misconceptions. The diagram of conceptual level percentages aims to observe the reduction of misconceptions between pretest and posttest results. Additionally, evaluation is carried out using student and teacher questionnaires to assess the test instruments and teaching materials qualitatively, including interviews with students and observation sheets for PBL based on ESD. Utilizing technology, such as Arduino, in the learning process makes the lessons more engaging. The use of technology and e-learning materials, as innovative teaching methods, allows students to learn from various sources (Yaniawati et al., 2020). The following are the results of the pretest and posttest for the 4-Tier Diagnostic Numeracy Test:

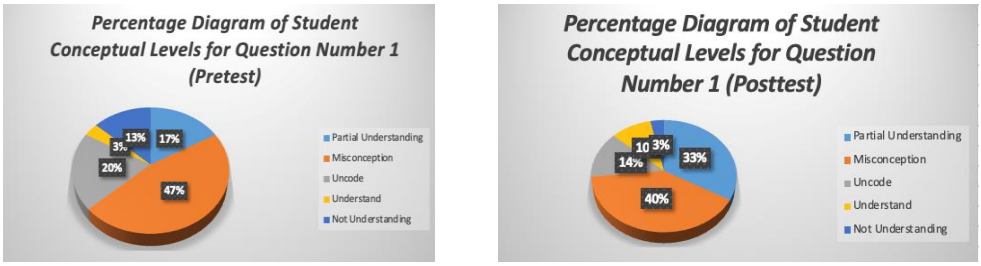


Figure 6. Diagram of Student Conceptual Level Percentages for Pretest and Posttest

Table 3. Summary of Student Conceptual Levels After Receiving PBL Based on ESD Treatment

Student Number	Tier For Question No.1				Conceptual Level
	1.1	1.2	1.3	1.4	
1	1	S	0	S	PU
2	0	S	0	S	M
3	-	S	0	-	UC
4	0	S	0	S	M
5	1	S	0	S	PU
6	0	S	0	S	M
7	0	S	0	S	M
8	0	S	0	S	M
9	-	S	0	S	UC
10	-	S	0	S	UC
11	-	S	0	S	UC
12	0	S	0	S	M
13	1	S	0	S	PU
14	0	S	0	S	M
15	0	S	0	S	M
16	-	S	0	S	UC
17	0	S	0	S	M
18	1	S	1	S	U
19	1	S	1	S	U
20	1	S	0	S	PU
21	0	S	0	S	M
22	1	S	0	S	PU
23	1	S	1	S	U
24	-	S	0	S	UC
25	0	S	0	NS	NU
26	1	S	0	S	PU
27	0	S	0	S	M
28	1	S	0	S	PU
29	1	S	0	S	PU
30	0	S	0	S	M

Based on the results of SPSS 22 path analysis, as well as mean calculations and n-gain tests, several important findings indicate the effectiveness of this strategy in reducing students' misconceptions. The observation results during the pretest showed that there was a change and improvement in students' understanding. For instance, the percentage of students classified under the "understand" category increased from 3% in the pretest to 10% in the posttest. The percentage of students with "partial understanding" rose from 17% to 33%. Other categories also showed significant changes, indicating that misconceptions were effectively reduced. This success can be attributed to several key aspects of the research, which emphasize the model and teaching tools used in the learning process, thereby improving students' understanding of trigonometric ratio numeracy. These aspects include:

First, the implementation of the ESD-based PBL model has been shown to significantly improve students' conceptual understanding (Boye et al., 2023). ESD-based PBL provides real and relevant contexts for students, allowing them to relate numeracy concepts to real-world, sustainable issues. This encourages students to think critically and analytically in solving problems, thereby reducing the likelihood of misconceptions. Besides reducing misconceptions in this study, the PBL model also plays a crucial role in enhancing communication skills and mathematical connections (Firmansyah et al., 2020).

Second, the development of the 4-Tier Diagnostic Numeracy Test plays a crucial role in identifying and reducing misconceptions. This diagnostic test consists of four levels: (1) questions about basic concepts, (2) reasoning behind the answers, (3) students' confidence in their answers, and (4) identification of specific difficulties (Dina & Rosyidi, 2019). Through the analysis of diagnostic test results, teachers can gain a deep understanding of the areas of misconceptions students face and design appropriate interventions (Astuti et al., 2021).

The research results indicate that after the implementation of ESD-based PBL and the use of the 4-Tier Diagnostic Test, there was a significant reduction in the number of misconceptions experienced by students. Pretest and posttest data from observations suggest an improvement in students' understanding, as evidenced by better scores on the numeracy test and increased confidence levels in their correct answers. Additionally, students who learned with the ESD-based PBL approach showed a positive attitude toward numeracy learning. They were more motivated to learn and were able to apply the concepts learned in real-life contexts. The use of ESD contexts made students more aware of sustainable issues through previously unfamiliar teaching tools, thereby deepening their understanding and reducing misconceptions.

Overall, this study shows that the combination of ESD-based PBL and the development of the 4-Tier diagnostic numeracy Test is effective in reducing students' misconceptions. This approach not only enhances students' conceptual understanding but also develops critical and analytical thinking skills that are essential in numeracy learning and sustainable contexts. Sustainable learning with technology can enhance children's creativity in a contextual manner and enable them to face challenges and interact with each other without anxiety or hesitation during the learning process (Yaniawati et al., 2020).

b) Revisions

One form of revision related to tier-3 options involves replacing choices that are seldom selected by students. These options will be replaced by reasons provided by students through open-ended questions. Additionally, clearer instructions were created for filling out questions in tier-1, especially when the questions are deemed less suitable (Dina et al., 2019).

Based on the results from pretest and posttest, there were significant changes. In the pretest, there were 4 students in the "not understanding" group (students without the concept), which decreased to 1 student in the posttest. The "uncoded" group (students who did not answer the questions) had 6 students in the pretest, which decreased to 4 students. The "misconception" group (students with misconceptions) had 14 students in the pretest, which decreased to 12 students. The "partial understanding" group (students with incomplete concepts) had 5 students in the pretest, increasing to 10 students in the posttest. These changes align with Khoirin's research (Khoirin et al., 2023), which indicates an improvement in n-gain scores for literacy and numeracy in high categories with the implementation of PBL. Furthermore, the learning approach emphasizing sustainability with the addition of ESD in the teaching process has proven effective in guiding students in contextual learning (Ningsih et al., 2019).

5) Implementation

The subsequent implementation, if this research is successfully carried out, could serve as a reference for categorizing students based on their understanding of concepts as

complete, partial, nonexistent, or with misconceptions. This would enable teachers to provide appropriate treatment tailored to the abilities measured using the 4-Tier Diagnostic Test (Zulfikar et al., 2019). Students who have a complete understanding of concepts could act as peer tutors for their classmates in grasping trigonometric concepts and their applications. Numeracy questions in multiple-choice format alone may not fully assess students' abilities; therefore, innovative questions for both literacy and numeracy are needed to explore students' conceptual understanding more thoroughly.

CONCLUSION

This study has demonstrated that the use of Arduino-based mathematical teaching tools contextualized with the Problem-Based Learning (PBL) model grounded in Education for Sustainable Development (ESD) effectively reduces students' misconceptions in mathematics learning, particularly in numeracy. The results from the 4-Tier Diagnostic Test indicate a significant improvement in conceptual understanding among students after implementing this method. Additionally, students engaged in learning with Arduino-based teaching tools also showed increased motivation and involvement in the learning process, which in turn contributed to enhanced academic performance.

However, this study has several limitations. First, the research was conducted with a sample limited to 10th-grade students at a single school, so the results may not be generalizable to a broader population. Second, the implementation of technology-based teaching tools such as Arduino requires adequate resources, including both hardware and training for teachers to effectively utilize the technology. Third, the relatively short duration of the study may not be sufficient to observe the long-term effects of the applied teaching methods.

The contribution of this research is to provide new insights into reducing misconceptions in mathematics learning through innovative and contextual approaches. The implementation of Arduino-based mathematical teaching tools within the ESD-based PBL model can serve as a reference for educators and policymakers in designing more effective teaching strategies. Additionally, the 4-Tier Diagnostic Instrument used in this study can be a valuable tool for mapping and understanding students' conceptual understanding categories, which can ultimately help in designing more targeted educational interventions. Thus, this research has the potential to enhance the overall quality of mathematics education in Indonesia.

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