Development of an Augmented Reality-Based Learning Module on Isometric Transformation for Form 2 Students in Malaysia

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Abstract: Augmented Reality (AR) enhances education by providing immersive and interactive learning experiences, particularly for students with low spatial skills, as well as in conceptual and procedural knowledge. In the Malaysian Form 2 mathematics curriculum, Isometric Transformation presents significant challenges. Traditional teaching methods often fall short, leading to gaps in learning. AR facilitates real-time visualization, enhancing spatial reasoning and conceptual understanding.. Simultaneously, the learning module offers structured guidance, activities, and exercises to reinforce learning outcomes. This study examined the effectiveness of an AR-based learning module in enhancing students' spatial reasoning and their conceptual and procedural knowledge. The study involved 80 Form Two students from a public high school in Putrajaya. The researchers created tests based on the level of competence that students must achieve according to the Curriculum Standard Document and Form 2 Assessment (DKSP). The difficulty index testing is conducted following the guidelines set by Brookhart and Nitko (2018). The document analysis revealed that over 80% of Form 2 students in a public high school in Putrajaya, Malaysia, struggle with questions related to Isometric Transformation, indicating the students' weaknesses in spatial visualization and conceptual and procedural understanding. The analysis also showed that traditional teaching approaches may not adequately support students' learning needs. The results emphasize the potential of AR-based learning modules to provide targeted support, enhance comprehension, and improve performance in Isometric Transformation. This study highlights the need for innovative, technology-enhanced instructional methods to tackle these educational challenges.

Keywords: Augmented Reality, Isometric Transformation, Module Development, Spatial Visualization, Conceptual and Procedural Knowledge.

INTRODUCTION

The fast growth of technology in the 21st century has considerably impacted the teaching-learning experience, posing new challenges and broad consequences for educators. The rapid growth of technology in the education system significantly affects mathematics teaching and learning (Karim & Zoker, 2023). Students are eager to use Information and Communication Technology (ICT) in Mathematics classes, but traditional teaching methods used by teachers have kept academic performance unchanged (Mendoza-Rodríguez & Caranqui-Sánchez, 2024).

Tools like Mathematica software improved students' mathematical abstraction ability and independence in analytic geometry compared to traditional learning (Murtianto et al., 2019). Similarly, Dynamic Mathematics Software (DMS) such as GeoGebra has been particularly noted for its ability to facilitate quick calculations and assist students in abstracting complex mathematical ideas. This promotes discovery learning and enhances student engagement (Garba, 2019; Yerizon et al., 2021). Integration tools like the Ethnobra (Ethnomathematical Geogebra) learning model are practical and effective in enhancing students' geometry skills (Hamidah et al., 2024).

Technology creates immersive learning experiences through extended reality technologies, including Augmented Reality (AR), virtual reality, and mixed reality (Meccawy, 2022). These technologies provide interactive and engaging platforms for students to explore geometric shapes and spatial reasoning, making learning more exciting and effective (Hwang et al., 2021; Ipek et al., 2021).

AR is becoming more recognized as a valuable tool in mathematics education. Several studies have investigated the potential of AR to strengthen mathematics learning outcomes. Its ability to create interactive, real-world learning experiences makes it a powerful tool for teaching complex concepts (Sáez-López et al., 2020). By offering a mobile-based platform, AR allows a more engaging and practical understanding of mathematical principles (Angraini et al., 2022). For instance, AR boosts motivation and academic performance (Lam et al., 2023). Additionally, a study by Ahmad and Junaini (2020) demonstrated that AR allowed students to interact with 3D models, which enhanced their understanding of geometry.

Similarly, Fernandez-Enriquez and Delgado-Martin (2020) stated that AR positively contributed to a better interpretation of geometry, enhanced spatial visualization, and increased student motivation. Other than that, Flores-Bascuñana et al. (2020) discovered that AR helped 6th-grade students better comprehend shape concepts than the classical didactic method. In a different study, Pozo-Sánchez et al. (2021) examined the combined use of AR and the flipped classroom method, showing that both strategies contributed positively to the learning process. The flipped learning model enriches student-teacher interaction, autonomy, learning depth, classroom time utilization, and academic performance. Meanwhile, AR as a techno-educational tool boosts motivation, content accessibility, peer interaction, and problem-solving skills. Finally, Ahmad (2021) confirmed that AR boosts visual thinking in 10th-grade students learning geometry, compared to the traditional method. In conclusion, the findings from these studies confirm that AR is a technology that can significantly amplify specific skills and deepen students' discernment of geometry.

One key area where AR can be applied is in teaching Isometric Transformation, a crucial concept in mathematics. Isometric Transformation in mathematics preserves the distance between points in a given space. This type of transformation is essential in various fields, including signal processing, machine learning, and mathematics education (Kolouri et al., 2017). For instance, in the Malaysian Secondary School Mathematics Curriculum, Isometric Transformation is a fundamental topic (Nadarajan et al., 2023).

Isometric Transformation, which includes translations, reflections, rotations, and combinations, is complex for students to grasp. Research has shown that students often face difficulties executing and identifying these transformations, comprehending their underlying concepts, and overcoming misconceptions about their functionalities (Güven, 2012; Yanik, 2011). Students who face challenges in learning Isometric Transformation may face various obstacles in understanding the concept, subsequently affecting their performance. Various studies have explored teaching aids and instructional methods to optimize student achievement in Isometric Transformation.

Unlike conventional learning, Hamid et al. (2022) determined that non-digital games intensify engagement, motivation, and performance, especially when paired with cognitive-level questions. Similarly, Muhammad and Adnan (2023) developed *Transformasi Catur*. This chess-based game made learning more interactive, while Mohd Nasir et al. (2023) introduced the *Kit Transformasi Isometri*, which effectively improved student achievement and motivation. These studies highlight the benefits of game-based learning compared to traditional teaching methods.

However, most teaching aids developed are physical tools like colored cards and boards with storage and durability issues. Meisuri et al. (2023) suggest that technology-based teaching aids can overcome these limitations. In this context, Nadarajan et al. (2023) implemented a flipped classroom model to deepen Higher-Order Thinking Skills (HOTS), showing significant improvements in students' critical thinking and understanding compared to conventional instruction. Karatas (2022) and Mukamba & Makamure (2020) established that GeoGebra significantly improved students' understanding, problem-solving skills, and overall performance in Geometric Transformations compared to traditional methods. These studies highlight the importance of innovative teaching methods for Isometric Transformation. However, there is a gap in research on using AR to strengthen skills, specifically in Isometric Transformation.

Spatial abilities and conceptual and procedural knowledge are essential in learning Isometric Transformation. Research has indicated that students' spatial skills substantially impact their learning achievements when exposed to dynamic and static visualizations (Sudatha et al., 2018). Moreover, studies have highlighted the relationship between visual-spatial skills and mathematics ability, emphasizing the importance of spatial visualization ability for high achievement in mathematics (Bakker et al., 2022). Conceptual and procedural knowledge are both crucial in learning Isometric Transformation. In mathematics education, highlighting conceptual and procedural knowledge is essential for optimal learning outcomes (Hussein, 2022).

Visual-Spatial

Studies show that students face considerable challenges with spatial visualization skills, essential for understanding topics such as Geometry and Isometric Transformation (Gonzalez-Campos et al., 2022). Research indicates that effective technology integration in mathematics education can significantly improve students' spatial abilities, critical thinking skills, and overall academic performance (Sevari & Falahi, 2018; Paulo et al., 2022). AR strengthens students' spatial abilities, particularly in education, with significant benefits for those with low spatial visualization skills (Papakostas et al., 2021; Hawes & Ansari, 2020; Judd & Klingberg, 2021; Danakorn Nincarean et al., 2019). By transforming abstract concepts into tangible, interactive experiences, AR heightens students' spatial abilities, making complex ideas more accessible and engaging (Sukriadi et al., 2023; Masduki et al., 2022).

Furthermore, interactive AR has been claimed to provide cognitive benefits for learning over typical 2D interfaces, notably spatial visualization (Dünser et al., 2012). Studies showed that AR-based learning environments had a relatively more significant influence on low-spatial-ability students, indicating the potential of AR to benefit this specific group of learners (Phon et al., 2015). By allowing students to interact with 3D models in real-time, AR enables them to manipulate objects and directly observe the effects of transformations like translation, reflection, and rotation. This hands-on approach makes abstract concepts more tangible and comprehensible (Küçük et al., 2016). Moreover, AR can contextualize geometric concepts in real-world settings, facilitating better comprehension and retention among students, especially those who find abstract concepts challenging (Gerup et al., 2020). Additionally, AR can contextualize geometric concepts in real-world settings, assisting students in better relating to and understanding the material.

For students with low spatial abilities, AR provides a personalized learning experience where they can explore and grasp concepts at their own pace without pressure (Kase et al., 2023). Moreover, the potential of AR to offer highly realistic learning experiences suggests its applicability in helping students with low spatial-visual abilities to discern complex spatial concepts (Kamphuis et al., 2014). Research shows AR intensifies achievement and visual thinking in geometry students (Aldalalah et al., 2019), which is crucial since spatial skills directly impact mathematical performance (Qomario et al., 2022; Putri et al., 2022). AR enables hands-on interaction with 3D models, making transformations more tangible, improving understanding and retention (Yanuarto et al., 2024).

Conceptual and Procedural Knowledge

In learning Isometric Transformation, conceptual knowledge plays a crucial role in facilitating the understanding and application of novel procedures. Conceptual knowledge involves interpreting and understanding the relationships between concepts, which is essential for profoundly understanding the subject (Arslan, 2010). Students' misconceptions and lack of conceptual knowledge in geometry can significantly impact their performance in examinations (Luneta, 2015). Nasir et al. (2023) stated that students had difficulty understanding the concepts of translation, reflection, and rotation. They also face challenges in comprehending the variations involved in carrying out and identifying these transformations and their combinations (Olson et al., 2020; Rollick, 2009). These challenges are compounded by traditional teaching methods that may not sufficiently address today's students' visual and interactive learning needs.

Bodensiek et al. (2019) emphasize that AR has been a focal point of educational research as it can boost conceptual understanding and facilitate effective learning. Socrates and Mufit (2022) found that integrating AR into physics learning can heighten conceptual understanding, increase interest in education, and optimize critical thinking skills. Solikhin et al. (2022) studied the impact of AR-based learning media on chemistry students' conceptual understanding, highlighting the positive effects of AR on learning outcomes. Furthermore, Putra et al. (2022) reported that AR technology received positive feedback for helping students visualize complex concepts in 3D, hence increasing their knowledge. Additionally, Rohendi and Wihardi (2020) showed that mobile-based AR can facilitate more apparent teaching of 3D geometry shapes, leading to faster comprehension among students.

Procedural knowledge in learning Isometric Transformation involves understanding how to perform specific tasks or procedures related to Isometric Transformation. Procedural knowledge consists of understanding mathematical symbols and algorithms necessary for problem-solving (Mutawah et al., 2019). The relationship between conceptual and procedural knowledge is vital for developing mathematical competencies (Schneider & Stern, 2010). Conceptual knowledge provides the cognitive control needed to execute algorithms correctly, while procedural knowledge contributes to understanding mathematical concepts (Sáenz, 2008). Both types of knowledge are essential for students' mathematical development (Lenz & Wittmann, 2020).

In mathematics education, conceptual knowledge should be taught before procedural knowledge to boost learning outcomes (Rittle-Johnson et al., 2001). Research has shown that AR facilitates contextualization and individualization of training, enabling students to practice and apply procedures in diverse contexts, ultimately leading to better mastery (Barsom et al., 2016). Fauziah and Sulisworo (2019) reported significant improvements in students' performance after using AR-based learning media, indicating that such technologies can effectively bridge the conceptual and procedural knowledge gap. Moreover, AR offers immediate feedback on tasks, allowing students to rectify mistakes in real time, reinforcing learning, and improving procedural knowledge (Dutta et al., 2022; Moro et al., 2021).

Learning Module

Sidek and Ariffin (2011) state that the learning module helps students master and apprehend a subject more clearly. Similarly, Nugroho et al. (2019) describe the learning module as a complete unit of learning explicitly designed for students to use either for self-learning or in the classroom. Efforts have been made to develop learning modules to strengthen understanding and foster interest in Mathematics (Marham et al., 2023; Ibrahim et al., 2020). The use of learning modules has been proven to amplify student learning outcomes across various subjects, including Mathematics (Basari & Moi, 2022), Science (Jumaat et al., 2022), Entrepreneurship (Ahmad & Siew, 2022), and History (Kaviza, 2021).

Modules can be integrated with technology, such as e-modules with computing media (Siregar & Harahap, 2020) and video-based learning modules (Kamlin & Keong, 2020). M-learning modules further elevate flexibility, enabling learning anytime and anywhere (Ismail & Kob, 2023). This integration significantly optimizes student performance through diverse technological approaches. Previous research has also found that integrating technology, specifically AR within learning modules, significantly impacts student learning outcomes more than using technology alone or a module without technological enhancements.

For instance, Nadzri et al. (2023) developed an AR-based learning module for Ruang, demonstrating that Year 4 students in the treatment group achieved higher mathematics performance than the control group using a learning module without AR integration. Similarly, Dewi and Kuswanto (2022) evaluated an AR-based physics e-module that effectively improved mathematical communication and critical thinking skills among Grade 12 students compared to the conventional teaching method. Their analysis confirmed the module's effectiveness in enhancing these abilities. In the field of chemistry, Whatoni and Sutrisno (2022) developed an AR learning module for Chemical Bonding, which significantly increased upper-secondary students' interest and motivation, with apparent differences observed between pre-and post-intervention results. Additionally, Pratamadita and Dwiningih (2022) developed an interactive e-module for Visual-Spatial Training that effectively advanced the spatial intelligence of Grade 10 students.

Their research found a significant difference between pretest and posttest results, indicating that the interactive 3D elements in the e-module positively impact students' visual-spatial intelligence. The 3D interactive elements allowed students to construct concepts and independently elevate their understanding of intermolecular forces. Past studies have shown that learning modules boost students' achievement and specific skills. The effectiveness of these modules highlights their potential to optimize learning processes and educational outcomes, providing valuable insights for developing more effective learning modules in the future.

Despite the potential of AR and learning modules, their application in Malaysian education, particularly in teaching Isometric Transformation, remains limited. Most AR resources focus on other geometry or mathematics topics, leaving a gap in addressing students' challenges with visual-spatial, conceptual, and procedural understanding of Isometric Transformation. This highlights the need for a comprehensive needs analysis to develop a well-structured AR-integrated learning module specifically for Form 2 students in Malaysia.

RESEARCH OBJECTIVE

This study was conducted based on the researcher's need to obtain information about the topic, characteristics, and teaching module specifications that want to develop. Therefore, the objectives of the study are:

1. To identify students' difficulties in spatial visualization related to understanding and applying Isometric Transformation based on their test performance.
2. To analyze the conceptual and procedural knowledge gaps in students' understanding of Isometric Transformation.
3. To assess how integrating AR-based learning modules can potentially address these challenges by improving students' spatial reasoning, conceptual understanding, and procedural execution of Isometric Transformation.

RESEARCH QUESTION

The research questions for the needs analysis phase are as follows:

(a) How do the students experience spatial visualization when answering questions about the Isometric Transformation topic?
(b) How do the students demonstrate their level of conceptual and procedural knowledge of the Isometric Transformation topic while answering related questions?
(c) How does integrating an AR-based learning module improve students' spatial reasoning, as well as their conceptual and procedural knowledge of Isometric Transformation?

METHODS

This study utilizes the method of analyzing test responses, which examines students' answer scripts on the topic of Isometric Transformations for Form 2.

Sample

This study was conducted at a public high school in Putrajaya. Eighty students from three classes were randomly selected using a simple random sampling method from a total of 231 students across seven classes. This approach ensures that the sample is representative of the entire population, allowing for the study's results to be generalized to the broader group of Form 2 students.

Procedure

Students learned about Isometric Transformation through traditional teaching methods without incorporating AR. This phase lasted for the standard duration as outlined by the school curriculum. After completing the traditional teaching phase, students were administered the achievement test on how they experienced spatial visualization in answering questions related to the Isometric Transformation topic and demonstrated their conceptual and procedural knowledge while answering related questions.

Instrument

The achievement test consisted of subjective questions adapted from items in the KSSM Mathematics textbook, focusing on the performance levels outlined in the DSKP Mathematics Form 2 curriculum for the Isometric Transformation topic. The administered test included four sections with a total of ten main questions. This achievement test comprised ten questions specifically targeting performance levels (TP) 1 to 4. This approach was chosen because these test items are designed to assess the basic and intermediate skills essential for subject mastery at this educational level. By restricting questions to TP 1 to TP 4, we ensure that all students grasp the necessary fundamentals before progressing to more complex concepts. This design guarantees that the test effectively evaluates students' knowledge of Isometric Transformation in alignment with the Mathematics Form 2 DSKP. Table 1 displays the mapping of the administered test against the curriculum specifications for the Isometric Transformation topic of Form 2.

In contrast, Table 2 shows the percentage distribution of the questions according to TP. Students are required to answer this test in 60 minutes. Each question carries a maximum of four marks.

Category	Question	Sub Question	Performance Level (TP)
Translation, Reflection, Rotation	1		TP 1
	2		TP 2
	3	a	TP 3
		b	TP 3
	4		TP 4
Translation	1	a	TP 1
		b	TP 2
		c	TP 3
	2	a	TP 1
		b	TP 2
		c	TP 3
Reflection	1	a	TP 1
		b	TP 2
		c	TP 3
	2	a	TP 1
		b	TP 2
		c	TP 3
Rotation	1	a	TP 1
		b	TP 2
		c	TP 3
	2	a	TP 1
		b	TP 2
		c	TP 3

Table 1: Performance Test Mapping of Isometric Transformation.

Performance Level	Number	Percentage
TP 1	7	30.4
TP 2	7	30.4
TP 3	8	34.8
TP 4	1	4.4

Table 2: Percentage Distribution of Questions According to Performance Level (TP).

Difficulty Index

Difficulty index testing was conducted to verify that the constructed test items accurately assess the difficulty levels, categorized as easy, medium, or hard. Tables 3 and 4 demonstrate each question's difficulty index value and interpretation. Difficulty index testing for subjective items was made by referring to Brookhart and Nitko (2018) with calculations as below:

$$DifficultyIndex = \frac{(Averagemark - Minimummark)}{(Rangemark - Minimummar\ \ )} \quad (1)$$

Value	0.00-0.20	0.21-0.40	0.41-0.60	0.61-0.80	0.81-1.00
Interpretation	Too hard	Hard	Medium Hard	Easy	Too Easy

Table 3: Difficulty Index Value and Interpretation.

Category	Question	Sub Question	Difficulty Index	Interpretation
Translation, Reflection, Rotation	**1**		0.88	too easy
	2		0.08	too hard
		a	0.18	too hard
	3	**b**	0.06	too hard
	4		0.10	too hard
Translation		**a**	0.13	too hard
	1	**b**	0.10	too hard
		c	0.07	too hard
		a	0.06	too hard
	2	**b**	0.06	too hard
		c	0.04	too hard
Reflection		**a**	0.03	too hard
	1	**b**	0.03	too hard
		c	0.04	too hard
		a	0.03	too hard
	2	**b**	0.03	too hard
		c	0.02	too hard
Rotation		**a**	0.00	too hard
	1	**b**	0.00	too hard
		c	0.00	too hard
		a	0.00	too hard
	2	**b**	0.00	too hard
		c	0.00	too hard

Table 4: Difficulty Index Interpretation of Test Questions.

Question 1 on translation, reflection, and rotation proved too easy for most students, with a difficulty index of 0.88. However, many other questions were excessively difficult, showing difficulty indices ranging from 0.00 to 0.20. The low difficulty index for numerous questions suggests that the current teaching approach may not be effective enough to help students grasp the key concepts of Isometric Transformation. Traditional teaching methods, such as lectures and textbook exercises, might not engage students sufficiently or cater to their diverse needs, limiting their ability to develop both conceptual and procedural knowledge. These methods often fail to enable students to interact with the material in a hands-on and meaningful manner. Given that Isometric Transformation requires strong spatial reasoning skills, students may struggle to visualize the concepts without appropriate tools, such as visual aids, manipulatives, or technologies like AR. Therefore, teachers should reconsider their teaching methods and may want to incorporate more interactive strategies to assist students in better understanding the topic. Additional practice and the integration of teaching aids, such as AR, could alleviate the challenges that students encounter.

Data Analysis

To ensure the validity of the achievement test, the test items were carefully reviewed and validated by an expert mathematics teacher. Feedback from the expert was incorporated into the revision of the test, enhancing its content validity. Participants in the study were selected based on specific criteria. For confidentiality, their names were replaced with labels from P1 to P80. After collecting the answer scripts, the researcher meticulously checked each one against a verified marking scheme, assessing how well students understood the Isometric Transformation.

For data analysis, the researcher organized and reviewed all scripts in line with the approved marking scheme to ensure consistent and accurate scoring. Each test item's Difficulty Index was then calculated to gauge how challenging the questions were. Consequently, all scores were recorded in Microsoft Excel, where they were analyzed to identify performance trends and patterns. This analysis revealed students' challenges and pinpointed areas for additional focus. The findings will also be used to refine and optimize the design of the AR-based learning module to be developed, ensuring it better addresses students' needs and intensifies their learning experience.

RESULT AND DISCUSSION

Document analysis methods were employed to address the research questions. Each student's achievement test answer script is reviewed and analyzed. The findings indicate that most students struggle with conceptual and procedural knowledge regarding Isometric Transformation across all questions. Table 5 presents the number of students categorized by the specified mark range for each question, evaluated according to the conceptual and procedural knowledge rubric.

Category	Question	Sub Question	Knowledge	Score					
				4	3	2	1	0	Not answer
Translation, Reflection, Rotation	1		Conceptual	72	0	0	4	4	0
	2		Conceptual	1	0	0	23	19	37
	3	a	Procedural	16	0	0	0	35	29
		b	Procedural	5	0	0	0	38	37
	4		Procedural	4	2	1	11	18	44
Translation	1	a	Conceptual	9	4	0	0	23	44
		b	Procedural	9	0	0	0	13	58
		c	Procedural	5	0	1	3	11	60
	2	a	Conceptual	3	3	1	0	6	67
		b	Procedural	3	2	1	0	7	67
		c	Procedural	2	1	1	2	6	68
Reflection	1	a	Conceptual	2	1	0	1	5	71
		b	Procedural	1	2	1	0	5	71
		c	Procedural	1	3	1	0	3	72
	2	a	Conceptual	1	2	0	0	2	75
		b	Procedural	0	3	0	0	2	75
		c	Procedural	0	2	0	0	2	76
Rotation	1	a	Conceptual	0	0	0	0	3	77

	b	Procedural	0	0	0	0	1	79
	c	Procedural	0	0	0	0	1	79
	a	Conceptual	0	0	0	0	1	79
2	b	Procedural	0	0	0	0	1	79
	c	Procedural	0	0	0	0	1	79

Table 5: Analysis of Students' Conceptual and Procedural Knowledge Based on Test Scores.

Table 6 quantifies student performance. The first table breaks down the number of students by score ranges for questions, translation, reflection, and rotation. Consequently, it is further subdivided into conceptual and procedural knowledge categories. The data suggest that many students scored poorly, with a notable portion not answering many questions. For instance, zero scores were prevalent across various questions, especially in the procedural knowledge category. In the conceptual score analysis, most students (75%) fell within the 11-20% range, while 85% scored between 0-10% in procedural knowledge. These statistics underscore students' struggles with Isometric Transformation concepts and procedures, and the low proficiency levels suggest a need for educational intervention in these areas.

The analysis discovered that students faced more procedural problems than conceptual ones. This could be attributed to the nature of the subject matter. Isometric Transformation involves significant procedural knowledge, such as understanding translation, reflection, and rotation. These procedural demands require a deep understanding of mathematical concepts and precise execution, which can be challenging for students. Additionally, procedural knowledge often requires more practice and application than conceptual knowledge, which may contribute to the higher frequency of procedural problems among students. Mastery of procedural skills usually relies heavily on a solid understanding of the underlying concepts. Students who have not grasped the fundamental concepts may struggle to apply those procedures effectively. In education, it is crucial to ensure that students comprehend the concepts before advancing to procedural aspects, as this facilitates deeper and more enduring learning.

	Range Marks (%)					
Category	**51-60**	**41-50**	**31-40**	**21-30**	**11-20**	**0-10**
Conceptual	3	1	3	6	60	7
%	**3.75**	**1.25**	**3.75**	**7.5**	**75**	**8.75**

Table 6: Analysis of Students' Performance Based on Conceptual Knowledge Scores.

	Range Marks (%)					
Category	**51-60**	**41-50**	**31-40**	**21-30**	**11-20**	**0-10**
Procedural	1	2	0	2	7	68
%	**1.25**	**2.5**	**0**	**2.5**	**8.75**	**85**

Table 7: Analysis of Students' Performance Based on Procedural Knowledge Scores.

Based on the conceptual and procedural scores, the study of student performance revealed that many scored low in both categories. Further analysis indicated that most students face considerable challenges, particularly with the Isometric Transformation type of rotation, as shown by the high number of students who did not answer correctly in Table 5. The number of students who answered incorrectly for rotation is significantly higher than for translation and reflection, suggesting that rotation is the most challenging Isometric Transformation type. Unlike translation (which involves straightforward shifting) or reflection (which has a clear mirror effect), rotation requires turning an object around a fixed point, which can be difficult for students to visualize mentally, especially without interactive tools. Contributing factors may include a lack of understanding of the concepts and procedures related to Isometric Transformation.

Based on the results, students face significant challenges with procedural aspects rather than conceptual understanding in Isometric Transformation. While they may grasp that a shape remains unchanged in size and orientation after a transformation, correctly executing the steps can be difficult. This difficulty contributes to the challenge of visualizing movements. Recognizing that a shape is being reflected or rotated differs from confidently placing it in the correct position. Additionally, following the step-by-step process requires careful attention to detail; even a small mistake in identifying coordinates or selecting the appropriate transformation can lead to errors. This highlights the need for targeted interventions and support in teaching and learning Isometric Transformation concepts and procedures.

In addition, it was found that students did not master other topics related to Isometric Transformation, such as Coordinates, where students could not plot coordinate points well, as shown in Figure 1.

Question

1) Under a translation, the image of P (-2, 3) is P' (-7, -2).
   a) Describe the translation in form $\binom{a}{b}$.
   b) Determine the image coordinates of Q (2, 1) under the same translation.
   c) Determine the object coordinates of R' (-1, -2) under the same translation.

Student Answer

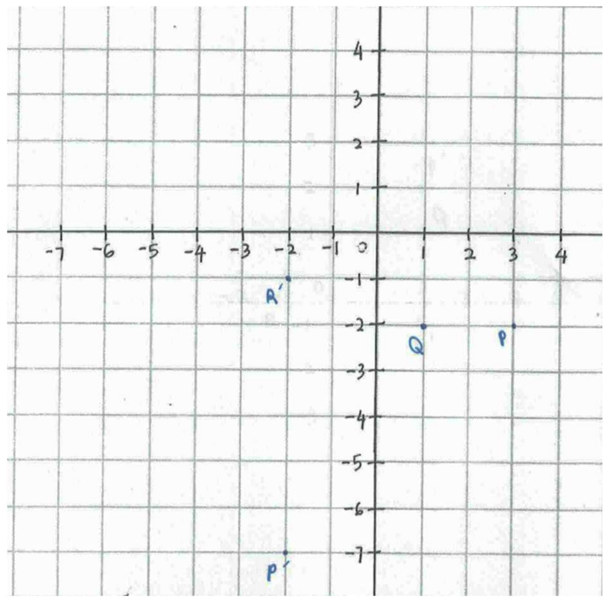


Figure 1: Example of Student Errors in Plotting Coordinate Points.

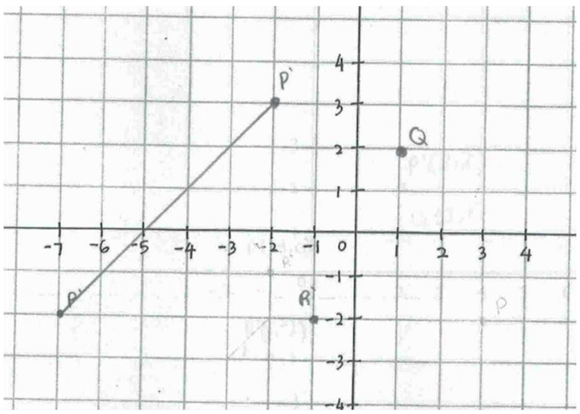
However, Figure 2 illustrates that the student has a basic knowledge of graphs. Specifically, he can plot coordinate points well but does not understand the concept of translation and reflection when he fails to perform translation correctly and determine the axis of reflection.

Student 1

Question

1) Under a translation, the image of P (-2, 3) is P' (-7, -2).
   a) Describe the translation in form $\binom{a}{b}$.
   b) Determine the image coordinates of Q (2, 1) under the same translation.
   c) Determine the object coordinates of R' (-1, -2) under the same translation.

Answer



Student 2

Question

1) R (3, 1) is mapped to R' (7, 1) under a reflection.
   a) Describe the reflection by stating the axis of reflection.
   b) Determine the image coordinate of (8, -5) under the same reflection.
   c) Determine the object coordinate of (1, 5) under the same reflection.

Answer

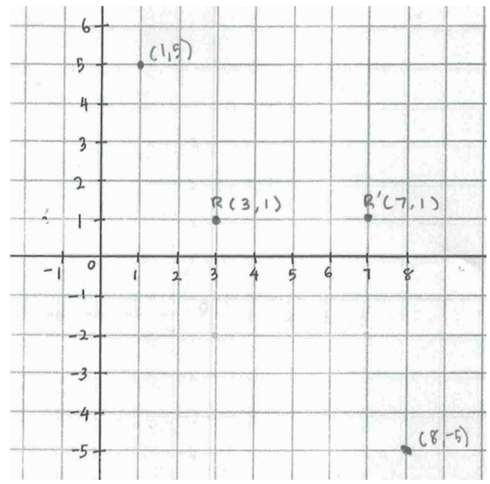


Figure 2: Student Responses Indicating Misunderstanding of Isometric Transformation.

Figure 3 illustrates the answers of students who got the highest marks among 80 students. When answering the question correctly, the first question shows the student's understanding of translation, reflection, and rotation concepts and procedures. Consequently, he can answer questions about translation and reflection well. This means that this student has good conceptual and procedural knowledge about Isometric Transformation. However, regarding the question about rotation, he did not answer, even though he was knowledgeable about it. This is likely because he could not visualize the concept of rotation, which prevented him from responding.

This demonstrates that he has a low visual-spatial ability. However, this is merely a researcher's assumption. A visual-spatial test on him could confirm this. The same observation can also be noted in the answer script of the student who received the second-highest score among all the students (Figure 4). Figures 3 and 4 illustrate the script of the student's answers.

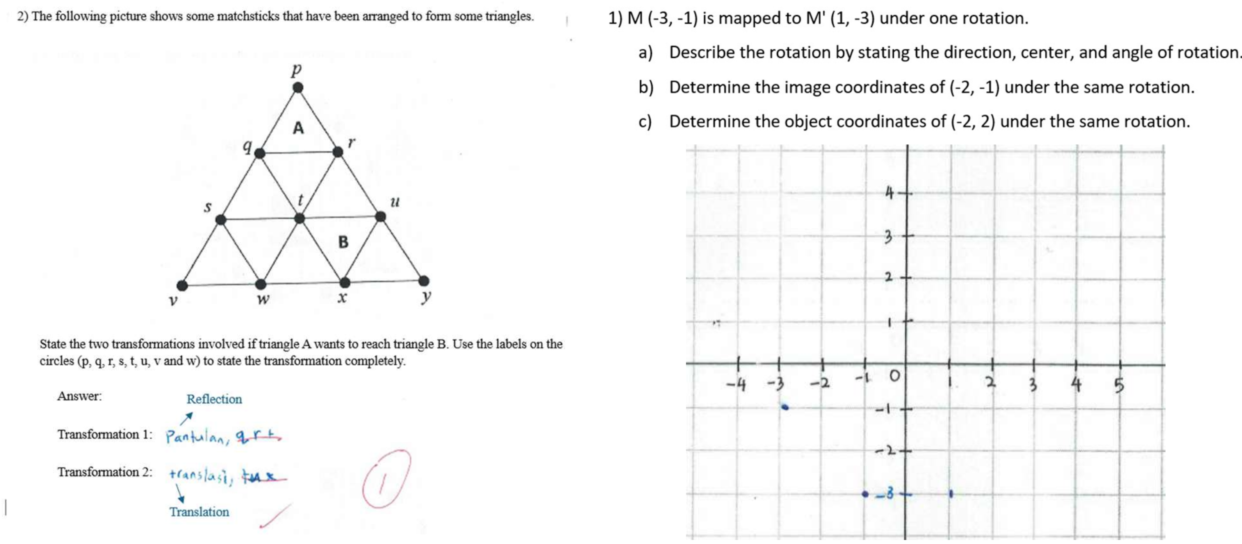


Figure 3: Answer Script of the Highest-Scoring Student in the Isometric Transformation Test.

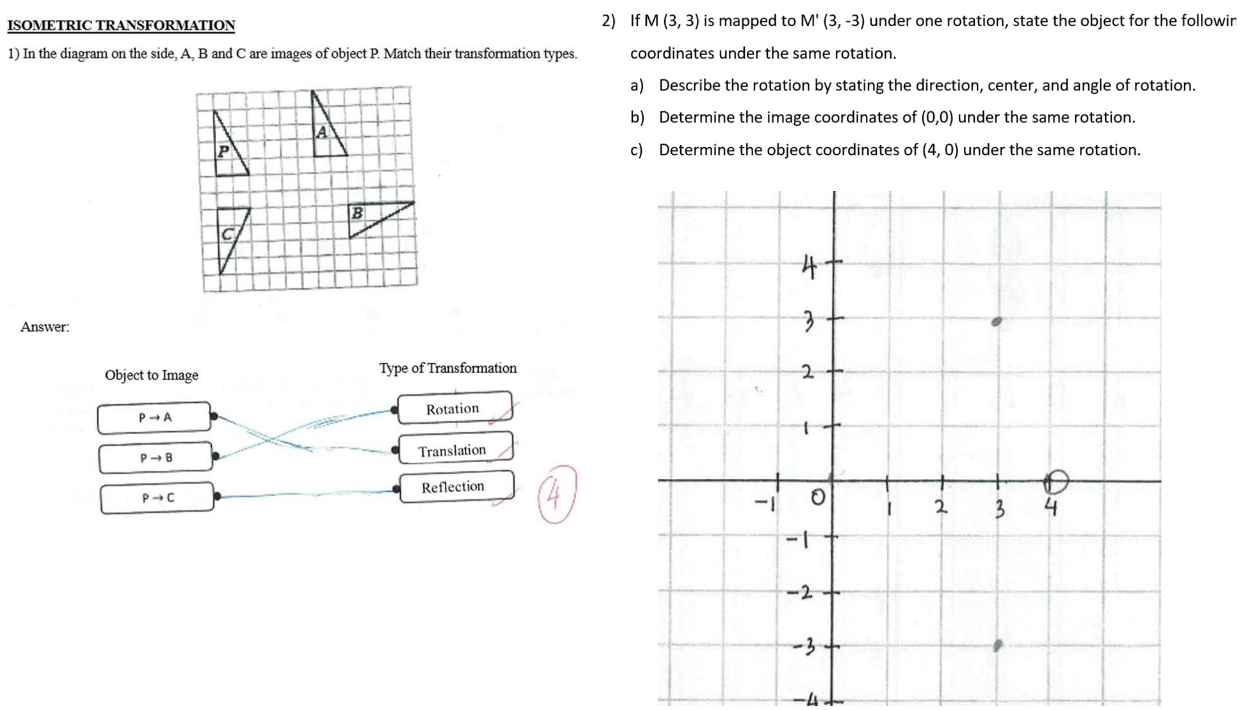


Figure 4: Answer Script of the Second Highest-Scoring Student in the Isometric Transformation Test.

The lack of responses from most students to the questions may be due to weaknesses in visualization, conceptual knowledge, and procedural knowledge. Poor conceptual understanding prevents them from fully grasping the fundamental ideas to answer the questions. At the same time, limited procedural knowledge makes it difficult for them to apply the correct steps to solve problems. Additionally, weak visualization skills hinder their ability to interpret spatial relationships, recognize patterns, and mentally manipulate shapes, making it challenging to understand and represent the tested concepts. This suggests that although some students understand the core ideas, they struggle to apply their knowledge in practice, particularly when following specific transformation steps. The gap between conceptual understanding, procedural execution, and visualization skills highlights students' difficulties in effectively performing transformation tasks without a well-developed spatial and conceptual foundation.

Therefore, it is necessary for the development of teaching aids that can assist students with low spatial visualization ability and be effective in improving conceptual and procedural knowledge to overcome this problem. AR has the potential to revolutionize the learning experience, particularly in the context of understanding complex mathematical concepts such as Isometric Transformation. By integrating AR technology into the learning module, students can engage in immersive and interactive experiences that deepen their ability to visualize and comprehend abstract concepts more effectively. AR bridges traditional teaching methods and student comprehension by providing real-time visualization of transformations and strengthening spatial reasoning, conceptual understanding, and procedural knowledge. Meanwhile, a structured learning module offers targeted guidance, activities, and exercises to reinforce these skills, ultimately enhancing student achievement in Isometric Transformation. Integrating AR and a structured learning module creates a dynamic and adaptive learning environment that caters to students' needs, enabling them to progress at their own pace while receiving immediate feedback. This innovative approach can potentially significantly elevate student achievement in Isometric Transformation.

CONCLUSION

This study highlights the critical need for a learning module integrating AR to enrich Form 2 students' understanding of Isometric Transformation in Malaysia. Traditional teaching methods have proven inadequate in addressing students' challenges with visualization, conceptual understanding, and procedural knowledge, leading to learning gaps. Moreover, analysis of student test performance confirmed significant struggles in these areas, reinforcing the need for AR-enhanced learning to bridge these gaps.

AR offers a transformative approach to learning transformations through real-time visualization and interactive exploration, particularly in enhancing spatial reasoning, conceptual grasp, and procedural execution. Unlike traditional methods reliant on static images, AR enables students to engage directly with 3D objects, fostering deeper comprehension of translation, reflection, and rotation. Furthermore, AR's ability to provide instant feedback supports procedural learning, helping students refine their understanding of transformation steps in real-time. In learning Isometric Transformation, students often struggle with spatial visualization and procedural execution, particularly when using traditional paper-based methods.

One of the key challenges in translation is ensuring that students understand how a shape moves without changing its orientation. In a conventional classroom, students are typically asked to plot a translated shape on graph paper by counting units. However, this process can lead to errors due to miscounting or misalignment. With AR, students can interactively select a 3D shape and apply a translation by dragging it to a new position while the app provides real-time confirmation of accuracy. Unlike manual plotting, this method reinforces conceptual understanding by allowing students to dynamically see and manipulate the transformation rather than relying on abstract visualization.

Similarly, the reflection of a shape across a line of symmetry is another area where students frequently encounter difficulties. Traditional exercises require them to manually mirror each vertex, often leading to incorrect placements and orientation errors. With AR, students can choose a quadrilateral in a virtual space, select the reflection axis, and observe how the shape flips in real-time. This allows them to instantly recognize how distances and orientations remain consistent while eliminating the guesswork of static images.

Among the most challenging transformations for students is rotation, which requires visualizing how each point moves in a circular path around a fixed point. In traditional methods, students often struggle to determine the correct quadrant, direction, and angle when performing a 90° or 180° rotation. They must rely on complex manual plotting techniques, which can be confusing, especially for those with low spatial reasoning skills. By contrast, an AR-based approach allows students to select a shape, choose a rotation point and angle, and see the transformation occur dynamically. This immediate feedback helps students correct errors, apprehend the relationship between rotation and coordinate changes, and build a more intuitive grasp of geometric transformations. Unlike static images, which only show the result, AR enables students to track the transformation as it happens, making the learning process more engaging and interactive.

A well-structured learning module is crucial in ensuring that AR integration is effective. Such a module provides clear instructional guidance and structured activities, making mathematical concepts more accessible and engaging. A strategic approach encompassing curriculum alignment, educator empowerment, and thoughtful instructional design is essential to integrate AR-based learning modules into Malaysian mathematics classrooms, particularly for topics like Isometric Transformation.

First, curriculum integration should ensure AR activities align with existing curricular goals, reinforcing key concepts without disrupting the syllabus. These modules should supplement traditional methods by visually visualizing abstract ideas, such as geometric transformations. Lessons should blend guided exploration, collaborative problem-solving, and structured practice while incorporating adaptive features to accommodate diverse learning paces and spatial reasoning abilities.

Second, educator readiness requires comprehensive teacher training through workshops and hands-on sessions to build technical proficiency and pedagogical confidence. Training should focus on seamless AR integration into lesson plans, real-time feedback techniques, and interactive quizzes for assessment. Establishing peer collaboration networks allows educators to share resources, refine strategies, and troubleshoot challenges, while sustained support through follow-up coaching and reflective practices ensures long-term adoption.

Third, successful classroom implementation depends on technology accessibility, ensuring schools have compatible devices such as tablets and smartphones and user-friendly AR applications. Digital or printed guides can streamline navigation, and lessons should begin with teacher-led AR demonstrations before transitioning to student-driven activities that encourage the manipulation of virtual objects to explore transformations. Peer discussions further deepen conceptual understanding and engagement.

Fourth, assessment and feedback mechanisms should combine formative tools, such as AR quizzes and real-time analytics, with summative evaluations, including student reflections and observations, to measure procedural mastery and conceptual grasp. Regular feedback from educators and learners will help refine the module design and address technical or instructional challenges.

Finally, sustainability and scalability require embedding AR training into pre-service teacher education programs to equip future educators with digital competencies. Institutional partnerships can support resource sharing and innovation. Consequently, periodic AR content and infrastructure updates, informed by emerging educational trends, will ensure continued relevance and expansion across classrooms. This cohesive strategy balances pedagogical innovation with practicality, ensuring that AR becomes an enduring and impactful component of mathematics education in Malaysia.

To successfully implement AR in the classroom, educators should consider a structured approach that strengthens engagement, deepens conceptual understanding, and ensures an effective learning experience. Align AR with learning objectives by integrating it into the curriculum to heighten understanding, especially for abstract concepts like Isometric Transformation. Choose simple, user-friendly AR tools like GeoGebra AR or Merge Cube that require minimal setup. Design interactive activities that promote problem-solving and exploration rather than passive viewing. Guide students with structured lessons using the 5E model to scaffold learning effectively. Encourage collaboration through group tasks that foster peer discussions and critical thinking. Finally, use AR-based quizzes and real-time analytics for formative assessments, providing instant feedback to track and amplify student progress.

Future research should examine how AR-based learning modules affect students' spatial abilities over time and how they can be applied to other areas of mathematics. This study highlights the immense potential of AR, especially when paired with a well-structured learning module, to transform the way students engage with mathematics. By making learning more interactive and immersive, AR helps students grasp complex concepts and keeps them motivated and invested in learning. Hence, integrating AR into education is not just about using new technology. Still, it is about creating more prosperous, meaningful learning experiences that impact students' understanding and retention of mathematical concepts.

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