Fuzzy Delphi-Guided Design of an AR-Based Module for Isometric Transformation: Enhancing the Potential for Achievement, Visualisation, and Motivation

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Abstract

This study aimed to achieve expert consensus on the essential components and key elements required to design and develop an augmented reality (AR)-based learning module, known as ISOMAR, to support students' achievement, spatial visualisation skills, and motivation in learning Isometric Transformation. A design and development research approach was employed using the Fuzzy Delphi Method (FDM), involving 16 experts from diverse fields, including mathematics education, instructional module development, augmented reality, and spatial visualisation. A 32-item questionnaire was developed based on five key dimensions: objective setting, content selection, learning strategies, media selection, and logistics selection. Data were analysed using Triangular Fuzzy Numbers (TFN). The findings revealed a strong consensus among experts regarding the main components of the ISOMAR module, indicating a high-quality design. The consensus met established criteria, with over 75% agreement, threshold values (d) below 0.2, and α-cut values above 0.5. All items across the five dimensions satisfied the TFN requirements and were accepted. As Isometric Transformation is a key topic in secondary mathematics curricula in Malaysia and internationally, the ISOMAR module demonstrates significant potential to enhance instructional quality. The integration of AR is expected to improve the delivery of abstract mathematical concepts, making learning more interactive and engaging while supporting teachers in facilitating clearer understanding. The validated elements of the ISOMAR module provide a strong foundation for the future development and implementation of AR-based learning tools that promote meaningful learning experiences.

Keywords: fuzzy Delphi method, design and development research, learning module, isometric transformation, spatial visualisation

Introduction

The 21st century has witnessed a profound transformation in education, driven largely by rapid technological advancement. These developments have significantly transformed the teaching and learning of mathematics (Ministry of Education, 2016). The integration of technology in schools offers numerous benefits, including enhanced critical and creative thinking, the development of multidimensional 21st century skills, and improved academic performance (Yılmaz, 2021). Moreover, technology facilitates the creation of immersive and interactive learning experiences through advanced technologies such as augmented reality (AR), virtual reality (VR), and mixed reality (MR) (Meccawy, 2022).

Integrating AR into education offers significant benefits, particularly in enhancing students spatial visualisation abilitie s (Phon et al., 2019). AR provides immersive, realistic experiences that facilitate the comprehension of complex concepts (Kamphuis et al., 2014), while simultaneously boosting student motivation and achievement across various educational domains. It enables learners to explore and interact with 3D learning objects, making the learning process more dynamic and engaging (Kamal & Junaini, 2019). Moreover, AR supports the integration of models, processes, animations, and simulations, thereby fostering more active and intuitive student interaction (Grodotzki et al., 2023). Additionally, it promotes creativity and interactivity, both of which contribute positively to learning outcomes (Kang et al., 2023).

Isometric Transformation is a fundamental component of secondary school geometry. However, previous studies have shown that students often struggle to master this concept due to its heavy reliance on spatial visualisation skills (Safrina et al., 2022; Shaimi et al., 2023). To address these challenges, various instructional tools have been introduced to improve student achievement in Isometric Transformation. Game-based approaches, such as non-digital games (Hamid et al., 2022), *Transformasi Catur* (Muhammad & Adnan, 2023), and the Kit Transformasi Isometri (Nasir et al., 2023), have demonstrated positive effects on motivation and performance. Technology-driven strategies, such as flipped classrooms (Nadarajan et al., 2023) and GeoGebra-based activities (Mukamba & Makamure, 2020; Karatas, 2022), have been shown to enhance students' critical thinking and conceptual understanding. Despite these advancements, research on the application of AR in the teaching and learning of Isometric Transformation remains scarce, highlighting a gap in the existing literature.

A learning module is a structured instructional tool designed to achieve specific educational objectives (Yusop, 2013). According to Noah and Ahmad (2005), a module is a systematically organised teaching resource that focuses on a particular topic to facilitate student learning. Its primary purpose is to clearly define instructional goals and organise learning activities in a coherent, structured manner. Prior research has demonstrated that the use of learning modules can significantly enhance student performance and motivation (Rahman et al., 2021).

Technological advancement has enabled researchers to integrate digital tools in mathematics instruction. For instance, Md Yunus et al. (2019) developed a geometry module using *Geometer's Sketchpad*, while Ramli et al. (2024) designed a calculus module for matriculation students based on a flipped classroom approach. Suryani et al. (2020) developed a GeoGebra-based module on space geometry, and Bakar and Ismail (2020) tested a tutorial-based mathematics module, demonstrating its effectiveness. Halimah et al. (2022) developed a mathematics module incorporating probing-prompting techniques to enhance motivation and learning outcomes. Similarly, Suyanti et al. (2021) designed a digital module based on Realistic Mathematics Education, which was found to be effective for lower secondary mathematics learning.

The integration of AR into instructional modules promotes flexible learning that aligns with students' learning styles (Mohd Nadzri et al., 2022). Furthermore, the effective use of instructional modules, when combined with appropriate educational technologies and adequate teacher training, can significantly enhance the quality of teaching and learning (Ismail & Daoh, 2021). Interactive and dynamic learning modules help students understand mathematical concepts in a more enjoyable and meaningful way, thereby increasing both motivation and academic achievement (Shamsudin & Surat, 2023). Numerous studies have consistently shown that learning modules positively impact mathematics education, particularly by improving students' motivation and performance. However, their application of such modules in classroom settings, especially for Isometric Transformation, remains limited, underscoring the need to develop a targeted AR-based module for this topic.

Spatial visualisation is a critical skill for mastering geometry, particularly Isometric Transformation (Gonzalez-Campos et al., 2022). AR has been shown to significantly enhance spatial skills, critical thinking, and overall mathematics performance (Sevari & Falahi, 2018; Papakostas et al., 2021; Paulo et al., 2022). By transforming abstract mathematical concepts into interactive 3D experiences, AR increases both accessibility and engagement (Masduki et al., 2022; Sukriadi et al., 2023). It is particularly beneficial for students with lower spatial abilities, as it allows real-time manipulation and provides contextual understanding of geometric objects (Phon et al., 2015; Küçük et al., 2016; Gerup et al., 2020; Kase et al., 2023). Collectively, these features contribute to improved learning outcomes and retention (Aldalalah et al., 2019; Qomario et al., 2022; Yanuarto et al., 2024).

Motivation plays a critical role in the learning process. It stems from both intrinsic factors (such as personal interest and curiosity) and extrinsic factors (such as rewards or consequences), both of which significantly influence learning outcomes (Ryan & Deci, 2000; Tohidi & Jabbari, 2012; Schunk & DiBenedetto, 2020). In mathematics education, student motivation is strongly correlated with academic achievement and engagement (Liu & Chu, 2010; Putri & Syahputra, 2019; Jehadus et al., 2022). Motivated students demonstrate deeper understanding and sustained interest in learning (Atmojo et al., 2021; Arthur et al., 2022). Empirical studies have confirmed that higher levels of motivation contribute to improved academic performance (Shum & Fryer, 2023; Li & Kutty, 2023). AR-based learning environments have also been shown to significantly enhance student motivation, satisfaction, and engagement, especially in geometry topics (Yousef, 2020; Bhagat et al., 2021; Tsai & Lai, 2022). Moreover, collaborative learning within AR contexts has been found to increase participation and achievement (Sarkar et al., 2020; Poçan et al., 2023). In summary, integrating AR into learning modules can address key challenges in teaching and learning Isometric Transformation by enhancing spatial visualisation and student motivation, two factors critical to student success in mathematics.

The Delphi method is a widely used approach for gathering expert consensus on a specific issue. One of its key strengths is its ability to support diverse empirical techniques, including the Fuzzy Delphi Method (FDM). FDM is an enhancement of the traditional Delphi technique, initially introduced by Kaufman and Gupta in 1988. It combines the classical Delphi method with fuzzy set theory to more effectively address ambiguity and uncertainty in expert judgment (Yusop, 2013). Fuzzy set theory, first proposed by Zadeh (1965), extends classical set theory by evaluating elements on a continuum between 0 and 1, rather than using binary classifications. This allows for more nuanced assessments and improved decision-making.

This study employs FDM to identify the critical elements and core components required to design and develop the ISOMAR module, an AR-based instructional module for Isometric Transformation. The use of FDM aims to achieve consensus among four categories of experts: those in learning module development, spatial visualisation, mathematics education, and augmented reality. These expert groups were selected to ensure the inclusion of essential elements and to identify key factors to consider in each module component. Therefore, this study aims to identify and validate, through the Fuzzy Delphi Method, the essential components of an AR-based instructional module (ISOMAR) for Isometric Transformation. This conceptual framework illustrates how AR is intended to support spatial visualisation and motivation, both of which are critical to facilitating students' understanding of Isometric Transformation. Table 1 presents the conceptual relationships between AR, spatial visualisation, motivation, and the learning of Isometric Transformation that underpin the design framework of the ISOMAR module.

Table 1

Conceptual links between augmented reality, spatial visualisation, motivation, and Isometric Transformation

Construct	Role in ISOMAR Design	Conceptual Contribution to Learning Isometric Transformation
AR	Instructional technology is embedded in the learning module.	Provides immersive and interactive digital representations of geometric objects, enabling real-time manipulation and exploration of transformations.
Spatial Visualisation	Core cognitive skill targeted in module design.	Supports students' ability to mentally translate, reflect, and rotate objects, which is essential for understanding Isometric Transformation.
Motivation	Affective factor supported through AR-enhanced learning experiences.	Enhances student engagement, interest, and persistence in learning abstract geometric concepts.
Isometric Transformation	Target mathematical content.	Involves spatially demanding concepts that benefit from visual, interactive, and motivating instructional support.

Research Aims

This study aims to establish expert consensus on the design of a learning module on Isometric Transformation using the FDM.

Methodology

This study employs the Design and Development Research (DDR) approach proposed by Richey and Klein (2007), which is widely adopted in educational development research, particularly in the creation of modules, models, and instructional designs. DDR typically involves multiple stages, including needs analysis, design and development, and evaluation. In alignment with this framework, the present study focuses specifically on the needs analysis and design validation stages. Accordingly, this article reports the identification and validation of essential components for the ISOMAR module through expert consensus using the FDM. The subsequent stages, including module development, implementation, and empirical evaluation of learning outcomes, will be addressed in future research.

The analysis was conducted in two phases. In the first phase, a review of relevant literature was conducted to identify essential elements for developing an AR-based learning module on Isometric Transformation. In the second phase, the FDM was used to obtain expert consensus on the module's content and structure. Experts evaluate the proposed components using a structured instrument, and consensus is analysed to refine and validate the module's design.

Sampling Procedure

This study employed purposive sampling, which is considered appropriate for obtaining expert consensus on predetermined elements. Hasson, Keeney, and McKenna (2000) identified purposive sampling as the most suitable strategy for the FDM. A total of 16 experts participated in this study, selected for their qualifications and relevant expertise, as detailed in Table 2. According to Adler and Ziglio (1996), the recommended number of experts ranges from 5 to 10 for homogeneous groups and from 10 to 15 for more diverse panels.

Table 2

Profile of experts involved in the Fuzzy Delphi study

Field of expertise	Educational level			Gender	
	Degree	**Master**	**PhD**	**Male**	**Female**
Mathematics Education	13			2	11
Augmented Reality		1			1
Visualisation			1	1	
Learning Module			1	1	
Total		**16**			**16**

As shown in Table 2, 16 experts participated in this study, representing diverse yet complementary areas of expertise relevant to the design of the ISOMAR module. The panel was predominantly composed of experts in mathematics education (n = 13), supported by specialists in AR, spatial visualisation, and learning module development, ensuring both pedagogical and technological perspectives were adequately represented. In terms of academic qualifications, all experts held at least a bachelor's degree, with the minority possessing masters and doctoral -level qualifications, reflecting a high level of scholarly and professional expertise. The expert panel also demonstrated a balanced gender distribution, with representation from both male and female experts. Overall, the composition of the expert panel highlights a strong depth of experience and interdisciplinary coverage, supporting the credibility and robustness of the consensus obtained through the FDM.

Expert Criteria

Sixteen experts were selected using purposive sampling, consistent with the FDM (Hasson et al., 2000). The selection followed strict criteria, requiring at least 7 years of experience, although the experts experience ranged from 6 to 21 years. The panel size conforms to the recommendation by Jones and Twiss (1978), who suggest involving 10 to 50 experts in Delphi studies. Additionally, experts with five to ten years of experience are also considered valid contributors (Creswell & Creswell, 2018). Willingness to participate was also considered.

Experts were defined as individuals with relevant qualifications, professional experience, training, affiliations, and peer recognition (Booker & McNamara, 2004; Nikolopoulos, 2004; Perera, Drew & Johnson, 2012). According to Cantrill, Sibbald, and Buetow (1996) and Mullen (2003), expertise is characterised by substantial knowledge and skill in a specific domain. In FDM research, appropriate expert selection is crucial to ensure the validity and reliability of the findings (Mustapha & Darusalam, 2017). Accordingly, all selected experts possessed qualifications directly aligned with the study. Table 3 shows the FDM procedure applied in this study.

Table 3

Steps of the FDM applied in this study

<table>
<tr><th>Step</th><th>Formulation</th></tr>
<tr><td>1. Expert selection</td><td>A total of 16 experts participated in this study, forming an expert panel to evaluate the significance of assessment parameters related to the factors under investigation. The panel also identified and defined potential issues pertinent to the module’s design and implementation using linguistic variables.</td></tr>
<tr><td>2. Determining linguistic scale</td><td>This process involves converting linguistic variables into Triangular Fuzzy Numbers (TFNs), represented as (m1, m2, m3), where m1 represents the minimum value, m2 represents the most plausible value, and m3 represents the maximum value. This conversion process transforms qualitative expert judgments into quantifiable fuzzy values, allowing uncertainty and subjectivity in expert opinions to be systematically modelled (Hsieh, Lu, & Tzeng, 2004). TFNs are used to develop a fuzzy scale that translates qualitative expert judgments into quantifiable fuzzy values.

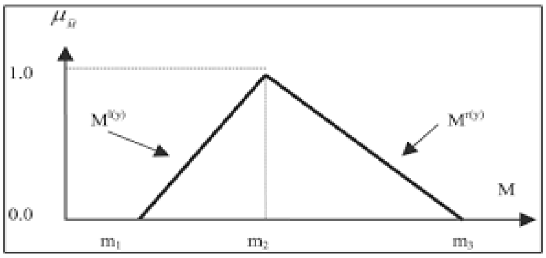

Figure 1: Triangular fuzzy number</td></tr>
<tr><td>3. The Determination of Linguistic Variables and Average Responses</td><td>After data collection, all expert responses were converted into fuzzy scales through a process known as response aggregation. The fuzzy values from all experts were averaged to obtain a single average fuzzy number for each item, representing the collective expert judgment (Benítez, Martín, & Román, 2007).</td></tr>
<tr><td>4. The determination of the threshold value "d"</td><td>The threshold value “d" is used to measure the degree of consensus among experts. The distance between two triangular fuzzy numbers $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ is calculated using the following formula (Thomaidis, Nikitakos, & Dounias, 2006):

$$d(\tilde{m}, \tilde{n}) \sqrt{\frac{1}{3}[(m1 - n1)^2 + (m2 - n2)^2 + (m3 - n3)^2]}$$

An item is considered to have achieved expert consensus if the threshold value $d \leq 0.2$ and the percentage of expert agreement exceeds 75%.</td></tr>
<tr><td>5. Identify the alpha cut aggregate level of fuzzy assessment</td><td>

- Once expert consensus is achieved, each item is assigned an aggregated fuzzy number. The α-cut value represents the minimum acceptable level of agreement and is set to 0.5, the midpoint between 0 and 1 (Mustapha & Darussalam, 2017).
- Items with fuzzy scores meeting or exceeding this α-cut value are considered acceptable for inclusion in the module design.

</td></tr>
<tr><td>6. Defuzzification process</td><td>

- Defuzzification is performed to convert the aggregated fuzzy numbers into a single crisp value representing the overall importance of each item. In this study, the centroid (average) method was used, calculated using the following formula:

$$A = \frac{1}{4}(m_1 + 2m_2 + m_3)$$

This method was selected because it is widely used in educational FDM studies and provides a balanced representation of expert judgments (Mohd Jamil et al., 2014).

- An item is accepted if its defuzzification value A ≥0.5, as supported by Bojdanova (2006) and Tang and Wu (2010).

</td></tr>
</table>

Step		Formulation
7.	Ranking process	Finally, all accepted items were ranked based on their defuzzification values. Items with higher defuzzification scores were considered more important and were prioritised in the decision-making and module design process, as agreed upon by the expert panel (Fortemps & Roubens, 1996).

Instrumentation

The FDM research instrument was developed based on an extensive review of relevant literature. Questionnaires were developed based on insights from previous studies, pilot studies, and expert interviews (Skulmowski et al., 2007). Following Mustapha and Darussalam (2017), the instrument was shaped through expert interviews and focus group discussions. Okoli and Pawlowski (2004) emphasise that item development should begin with a literature review.

The questionnaire was designed after consulting five experts in mathematics education. It includes five main constructs derived from the Standard Curriculum and Assessment Document (DSKP), the cognitive theory of multimedia learning (CTML), constructivism (CT), the 5E model, higher-order thinking skills (HOTS), and Sidek's module development model (SM). A 7-point scale was used for responses, as it enhances the accuracy and reliability of results (Chen et al., 2011). To further facilitate responses, fuzzy values were mapped to a 1–7 numeric scale, as shown in Table 4.

Table 4

Linguistic scale and corresponding triangular fuzzy numbers

Item	Fuzzy number
Strongly disagree	(0.0, 0.0, 0.1)
Disagree	(0.0, 0.1, 0.3)
Somewhat Disagree	(0.1, 0.3, 0.5)
Neutral	(0.3, 0.5, 0.7)
Somewhat agree	(0.5, 0.7, 0.9)
Agree	(0.7, 0.9, 1.0)
Strongly agree	(0.9, 1.0, 1.0)

The questionnaire items were carefully developed to align with the identified constructs and to ensure comprehensive coverage of the relevant concepts. A panel of expert in the FDM reviewed these items to assess their clarity, relevance, and alignment with the research objectives. The finalised list of items served as the basis for the data collection phase, enabling a systematic evaluation of expert consensus on the proposed design of the learning module. Researchers highlighted the critical features of an academic module on Isometric Transformation in a literature review (Table 5). The researchers will next use the FDM to assess the experts validity and consensus regarding whether this aspect is appropriate for inclusion in this model.

Table 5

Initial components and theoretical foundations of the ISOMAR module

Initial item rank	Learning Objective Selection
Item1	DSKP
Item2	DSKP
Item3	DSKP
Item4	DSKP
Initial item rank	**Learning Content Selection**
Item1	DSKP
Item2	CT
Item3	CTML
Item4	CT
Item5	CTML
Item6	HOTS
Item7	HOTS
Item8	CTML
Initial item rank	**Learning Strategy Selection**
Item1	CT
Item2	CT
Item3	CT
Item4	CT
Item5	CT
Item6	CT
Item7	CTML
Item8	CT
Item9	CT
Item10	CT
Item11	CTML
Initial item rank	**Logistic Selection**
Item1	DSKP
Item2	SM
Item3	SM
Item4	SM
Initial item rank	**Media Selection**
Item1	CTML
Item2	CTML
Item3	CTML
Item4	CTML
Item5	CTML

Findings

This section presents the expert consensus on key aspects identified through the FDM. A total of sixteen experts responded to the questionnaire, and their inputs were analysed to determine the level of agreement. The findings are summarised in Tables 6-10. In Tables 6 to 10, "Value of the item" denotes the calculated threshold value (*d*) for each item. Items with $d \leq 0.2$ are considered to have achieved consensus. The column "Item ≤ 0.2" indicates the number of items satisfying this criterion, while "% of item ≤ 0.2" reflects the percentage of expert agreement. Items with threshold values (*d*) ≤ 0.2 and expert agreement exceeding 75% are considered to have achieved consensus.

Table 6

Fuzzy Delphi analysis results for the learning objective selection construct

Results	Item1	Item2	Item3	Item4
Expert1	0.052	0.058	0.049	0.102
Expert2	0.289	0.233	0.207	0.450
Expert3	0.105	0.159	0.187	0.157
Expert4	0.052	0.058	0.049	0.102
Expert5	0.052	0.233	0.207	0.157
Expert6	0.105	0.159	0.207	0.102
Expert7	0.052	0.822	0.049	0.102
Expert8	0.052	0.159	0.187	0.235
Expert9	0.052	0.058	0.049	0.102
Expert10	0.289	0.233	0.207	0.157
Expert11	0.105	0.159	0.187	0.235
Expert12	0.105	0.159	0.207	0.157
Expert13	0.105	0.159	0.049	0.102
Expert14	0.105	0.159	0.049	0.235
Expert15	0.105	0.159	0.049	0.450
Expert16	0.105	0.159	0.187	0.235

Statistics	Item1	Item2	Item3	Item4
Value of the item	0.108	0.03299	0.06127	0.01414
Item ≤ 0.2	4			
% of item ≤ 0.2	100%			
Average of % consensus	100	93.8	100	87.5
Defuzzification	0.896	0.856	0.840	0.804
Status	Accept	Accept	Accept	Accept

Table 6 summarises the analysis results for the learning objective selection construct, which comprised four items. The findings indicate that all items achieved strong expert consensus, with threshold values (*d*) ranging from 0.014 to 0.108, all below the accepted cut-off of 0.2. The percentage of expert agreement for all items exceeded 75%, with consensus levels ranging from 87.5% to 100%. The defuzzification values further supported these results, with all items exceeding 0.80. Accordingly, all learning objective items were accepted, confirming their relevance and importance for the ISOMAR module design.

Table 7

Fuzzy Delphi analysis results for the learning content selection construct

Results	Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8
Expert1	0.112	0.119	0.071	0.172	0.086	0.267	0.264	0.113
Expert2	0.053	0.119	0.082	0.035	0.070	0.128	0.264	0.113
Expert3	0.571	0.119	0.071	0.223	0.086	0.125	0.127	0.113
Expert4	0.112	0.059	0.082	0.172	0.086	0.125	0.127	0.057
Expert5	0.053	0.861	0.082	0.035	0.086	0.423	0.423	0.057
Expert6	0.112	0.119	0.071	0.223	0.086	0.128	0.127	0.113
Expert7	0.053	0.059	0.082	0.035	0.070	0.125	0.127	0.057
Expert8	0.112	0.119	0.071	0.223	0.307	0.125	0.127	0.057
Expert9	0.112	0.119	0.071	0.035	0.086	0.128	0.129	0.113
Expert10	0.281	0.273	0.322	0.223	0.307	0.125	0.127	0.057
Expert11	0.053	0.119	0.071	0.172	0.086	0.267	0.264	0.113
Expert12	0.112	0.119	0.071	0.035	0.070	0.125	0.127	0.057
Expert13	0.112	0.119	0.071	0.035	0.086	0.128	0.129	0.113
Expert14	0.112	0.119	0.071	0.172	0.086	0.125	0.127	0.869
Expert15	0.053	0.059	0.071	0.035	0.086	0.128	0.129	0.113
Expert16	0.112	0.059	0.082	0.035	0.070	0.128	0.264	0.113

Statistics	Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8
Value of the item	0.133	0.160	0.092	0.127	0.128	0.154	0.170	0.139
Item ≤ 0.2				8				
% of item ≤ 0.2				100%				
Average of % consensus	88	88	94	100	81	88	75	94
Defuzzification	0.890	0.883	0.913	0.833	0.892	0.777	0.779	0.888
Status	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept

The learning content selection construct, presented in Table 7, comprised eight items. The results demonstrate a high level of consensus across all content-related elements, with threshold values ranging between 0.092 and 0.170. All items met the consensus criteria, achieving agreement levels ranging from 75% to 100%. Defuzzification values for this construct ranged from 0.777 to 0.913, indicating strong expert endorsement of the proposed learning content. Consequently, all learning content items were retained for inclusion in the ISOMAR module framework.

Table 8

Fuzzy Delphi analysis results for the learning strategy selection construct

Results	Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8	Item9	Item 10	Item 11
Expert1	0.100	0.081	0.062	0.086	0.081	0.138	0.105	0.186	0.177	0.179	0.095
Expert2	0.100	0.073	0.062	0.086	0.081	0.029	0.052	0.079	0.059	0.049	0.095
Expert3	0.100	0.081	0.062	0.086	0.081	0.256	0.105	0.186	0.505	0.508	0.095
Expert4	0.054	0.081	0.062	0.086	0.073	0.029	0.052	0.079	0.059	0.179	0.095
Expert5	0.054	0.073	0.092	0.086	0.081	0.029	0.105	0.268	0.177	0.214	0.061
Expert6	0.100	0.081	0.062	0.086	0.081	0.138	0.105	0.186	0.177	0.179	0.095
Expert7	0.054	0.073	0.092	0.070	0.073	0.029	0.052	0.079	0.059	0.049	0.061
Expert8	0.054	0.073	0.062	0.307	0.073	0.256	0.289	0.079	0.505	0.214	0.298
Expert9	0.054	0.073	0.092	0.070	0.073	0.138	0.105	0.079	0.059	0.049	0.095

Results	Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8	Item9	Item 10	Item 11
Expert10	0.296	0.313	0.331	0.307	0.313	0.256	0.289	0.208	0.215	0.214	0.298
Expert11	0.100	0.081	0.062	0.086	0.081	0.138	0.105	0.186	0.177	0.179	0.095
Expert12	0.054	0.073	0.062	0.070	0.073	0.029	0.052	0.186	0.177	0.179	0.061
Expert13	0.100	0.081	0.062	0.086	0.081	0.029	0.052	0.079	0.059	0.049	0.095
Expert14	0.054	0.081	0.062	0.086	0.081	0.138	0.105	0.208	0.215	0.049	0.095
Expert15	0.100	0.081	0.062	0.086	0.081	0.138	0.105	0.186	0.177	0.049	0.061
Expert16	0.054	0.081	0.092	0.070	0.073	0.029	0.052	0.186	0.177	0.049	0.061

Statistics	Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8	Item9	Item10	Item11
Value of the item	0.089	0.092	0.086	0.110	0.092	0.112	0.108	0.216	0.186	0.149	0.110
Item ≤ 0.2						11					
% of item ≤ 0.2						100%					
Average of % consensus	100.0	93.8	93.8	87.5	93.8	100.0	100.0	93.8	87.5	93.8	100.0
Defuzzification	0.900	0.913	0.925	0.908	0.913	0.873	0.896	0.838	0.844	0.844	0.902
Status	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept

Table 8 presents the findings for the learning strategy selection construct, which consisted of eleven items. The results reveal that all learning strategy items satisfied the FDM consensus criteria, with threshold values below 0.2 and expert agreement exceeding 75% for each item. The defuzzification values ranged from 0.838 to 0.925, reflecting strong expert agreement on the suitability of the proposed instructional strategies. These findings suggest that the selected learning strategies are appropriate for supporting AR-based instruction in Isometric Transformation.

Table 9

Fuzzy Delphi analysis results for the logistics selection construct

Results	Item1	Item2	Item3	Item4
Expert1	0.071	0.075	0.135	0.062
Expert2	0.082	0.075	0.057	0.092
Expert3	0.071	0.604	0.135	0.062
Expert4	0.082	0.075	0.057	0.062
Expert5	0.071	0.075	0.545	0.062
Expert6	0.071	0.075	0.135	0.062
Expert7	0.082	0.088	0.057	0.092
Expert8	0.082	0.075	0.135	0.062
Expert9	0.071	0.075	0.135	0.062
Expert10	0.322	0.317	0.257	0.331
Expert11	0.071	0.075	0.135	0.062
Expert12	0.071	0.075	0.135	0.062
Expert13	0.071	0.075	0.135	0.092
Expert14	0.071	0.075	0.135	0.062
Expert15	0.082	0.075	0.545	0.092
Expert16	0.071	0.075	0.135	0.062

Statistics	Item1	Item2	Item3	Item4
Value of the item	0.090	0.124	0.179	0.086
Item ≤ 0.2	4			

Statistics	Item1	Item2	Item3	Item4
% of item ≤ 0.2		100%		
Average of % consensus	93.8	87.5	87.5	93.8
Defuzzification	0.919	0.915	0.873	0.925
Status	Accept	Accept	Accept	Accept

The analysis results for the logistics selection construct are shown in Table 9. All four logistics-related items recorded threshold values below 0.2, with expert agreement levels ranging from 87.5% to 93.8%. The defuzzification values, which ranged from 0.873 to 0.925, further indicate strong expert consensus. As a result, all logistics elements were accepted, highlighting their importance in ensuring the effective implementation of the ISOMAR module.

Table 10

Fuzzy Delphi analysis results for the media selection construct

Results	Item1	Item2	Item3	Item4	Item5
Expert1	0.081	0.043	0.062	0.071	0.062
Expert2	0.073	0.043	0.062	0.071	0.062
Expert3	0.081	0.043	0.062	0.071	0.062
Expert4	0.073	0.043	0.092	0.082	0.092
Expert5	0.081	0.043	0.092	0.082	0.092
Expert6	0.081	0.043	0.062	0.071	0.062
Expert7	0.073	0.111	0.092	0.082	0.092
Expert8	0.073	0.043	0.062	0.071	0.062
Expert9	0.081	0.043	0.062	0.071	0.062
Expert10	0.313	0.349	0.331	0.322	0.331
Expert11	0.081	0.043	0.062	0.071	0.062
Expert12	0.081	0.043	0.062	0.071	0.062
Expert13	0.073	0.043	0.062	0.071	0.062
Expert14	0.081	0.043	0.062	0.082	0.062
Expert15	0.081	0.043	0.062	0.071	0.062
Expert16	0.073	0.111	0.092	0.082	0.092

Statistics	Item1	Item2	Item3	Item4	Item5
Value of the item	0.092	0.071	0.086	0.090	0.086
Item ≤ 0.2			5		
% of item ≤ 0.2			100%		
Average of % consensus	93.8	93.8	93.8	93.8	93.8
Defuzzification	0.913	0.938	0.925	0.919	0.913
Status	Accept	Accept	Accept	Accept	Accept

Table 10 presents the findings for the media selection construct, which comprised five items. The results show that all media-related items achieved a high level of expert consensus, with threshold values ranging from 0.071 to 0.092 and expert agreement consistently exceeding 93%. The defuzzification values for this construct were all above 0.90, indicating strong agreement on the suitability of the selected media components for AR-based learning. Accordingly, all media selection items were accepted.

The analysis presented in Tables 5 to 9 indicates that all elements within the five main components of ISOMAR met the criteria established by the FDM, with threshold values (d) less than or equal to 0.2 and expert consensus greater than 75%. Additionally, a fuzzy score (A) greater than 0.5 further confirms expert agreement on the significance of these elements, validating their relevance and potential to enhance the effectiveness of ISOMAR.

Discussion and Implications

This study achieved expert consensus on the essential components of the ISOMAR learning module. The application of the FDM proved effective in eliciting expert insights and agreement from professionals in mathematics education, AR, spatial visualisation, and learning modules. The findings demonstrate the strong potential of AR integration in the design of instruction for Isometric Transformation, particularly in supporting students academic achievement, spatial visualisation skills, and motivation to learn.

The consensus reached by the expert panel affirms the relevance and appropriateness of the selected components and elements in the ISOMAR module for supporting learning in these three critical areas. Key elements identified include clearly defined objectives, media selection, content selection, logistical considerations, and appropriate learning strategies. These elements derived from CTML, CT, the 5E model, and the SM are recognised as essential for the effective design of ISOMAR. Their inclusion is crucial to ensuring the modules success in achieving its intended learning outcomes.

These results align with prior research indicating the effectiveness of AR in educational settings. For instance, studies by Nor and Mokhtar (2021) and Poobalan and Mahmud (2022) have highlighted ARs positive influence on students comprehension and interest. Similarly, Phon et al. (2019) emphasised ARs impact on enhancing spatial visualisation skills. The present study builds upon and reinforces these findings by proposing a structured AR-based learning module tailored to secondary-level mathematics.

The primary implication of this study lies in the development of a more effective and interactive AR-based learning module. ISOMAR has the potential to support student learning performance in Isometric Transformation by offering an engaging and immersive learning experience. AR allows students to better understand abstract geometric concepts by visualising and interacting with three-dimensional representations, thus strengthening spatial visualisation, a core skill in geometry. Moreover, the module may significantly enhance motivation to learn by making the learning experience more dynamic and enjoyable.

The consensus achieved through FDM provides a clear framework for designing future learning modules that meet students' cognitive and affective needs. Moreover, the ISOMAR module is expected to function as an effective instructional aid for teachers, facilitating more dynamic and meaningful instruction. With its interactive features, the module aims to spark student interest and foster deeper conceptual understanding of Isometric Transformation.

Despite the promising outcomes, the study acknowledges certain limitations. The panel of experts comprised only 16 individuals, the majority of whom were specialists in mathematics education. This may limit the diversity of perspectives, particularly from other relevant domains such as educational technology, instructional design, or cognitive psychology.

In conclusion, the study makes a significant contribution to mathematics education by introducing an AR-based learning module designed to improve the quality of teaching and learning. The successful application of FDM also underscores its value as a methodology for achieving expert consensus, which could be utilised in future research and development in educational innovation.

Beyond the design implications of the ISOMAR module, this study makes a notable methodological contribution by demonstrating the systematic application of the FDM within a DDR framework. The use of FDM enabled a structured, transparent process for eliciting expert consensus, reducing subjectivity in decision-making, and validating module components against predefined quantitative criteria. This approach ensures that the identified elements are not only theoretically grounded but also supported by collective expert judgment. As such, the methodology adopted in this study provides a replicable and rigorous model for future instructional design research, particularly in the development of AR-based learning modules.

Conclusion

This study aimed to design and develop an AR-based learning module for Isometric Transformation. Before the development process, a needs analysis was conducted to identify key components and elements that would inform the modules structure, including appropriate l earning activities and instructional strategies.

The findings of this study provide concrete input for the development of the ISOMAR module. This module has the potential to enhance students academic achievement, spatial visualisation, and motivation by providing an innovative and interactive learning environment. By integrating AR technology, the ISOMAR module aims to bridge the gap between abstract mathematical concepts and students understanding, ultimately supporting more meaningful and effective mathematics learning experiences.

Future Research

While this study has established a validated design framework for the ISOMAR module through expert consensus, subsequent phases of the DDR process remain to be undertaken. The next DDR phase will involve developing and piloting the ISOMAR module based on the validated components identified in this study. This will be followed by an empirical evaluation using quasi-experimental research designs to examine the module’s impact on students’ achievement, spatial visualisation skills, and learning motivation in authentic classroom settings.

In addition, longitudinal studies may be conducted in later DDR phases to investigate the sustained effects of AR-based learning on students’ cognitive development and motivation over time. Such studies would provide insights into the long-term effectiveness and scalability of the ISOMAR module.

Furthermore, future research may explore teachers readiness and professional development needs related to implementing AR-based instructional modules. Understanding teachers' technological competence, pedagogical beliefs, and institutional support will be essential for ensuring the successful adoption and integration of ISOMAR in classroom practice.

Finally, future DDR iterations could explore integrating emerging technologies, such as artificial intelligence (AI), with AR to develop more adaptive and personalised learning environments. This would further extend the instructional potential of ISOMAR and contribute to the advancement of technology-enhanced mathematics education

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