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# Framework on Teacher-Student Perspectives on Augmented Reality for Supporting Metacognitive Skills in Mathematics Problem Solving

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The Malaysian mathematics curriculum calls for mathematics problems which are advanced where solutions are not always clear. As a result, students tend to feel overwhelmed and have no idea how to begin the problem solving process. One of the reasons for students' difficulty in mathematics problem solving is their weakness in metacognitive skills characterized by planning, monitoring and evaluating. Augmented Reality (AR) combines real world objects to technological media to bring to life 2D diagrams and texts using hand-held devices. This study explores students and teachers' perspectives on how augmented reality can assist in supporting students' metacognitive skills in mathematics problem solving process. Interviews were conducted with three teachers and five students to extract the guidelines needed to be able to solve problems successfully by translating into the AR context. The study found that in the planning process animation and quick revision notes were needed, in the monitoring process animation on how the formula is used to solve the problem and in the evaluation process, image the step-by-step solution is requested. The developed framework was verified by seven experts through Content Validity Index (CVI) with a universal average of 0.96. The framework developed can be used in the future as a guideline for development of a mathematics problem solving module that integrates AR with metacognitive skills.

Keywords: augmented reality, framework, mathematics problems, metacognitive skills, problem solving, students perspectives, teachers perspectives

## INTRODUCTION

Metacognitive skills such as planning, monitoring, and evaluating play a critical role in enhancing students' mathematical problem-solving abilities and fostering academic independence (Kathayat, 2024; Nováková, 2024). Students with strong metacognitive awareness tend to perform better due to their ability to predict outcomes and self-assess

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their understanding (Nováková, 2024). Teachers can facilitate this development by integrating strategies that emphasize metacognitive thinking, adapting instruction to student needs (Restini et al.,2023; Reyes & Reyes, 2024). Recent studies stress the importance of intentionally embedding metacognitive practices throughout all education levels (Nováková, 2024). Moreover, such skills support self-discipline, time management, and self-learning (Abdullah, Rahman, & Hamzah, 2017; Bakar & Ismail, 2020; Wangguway et al., 2024 ). However, a gap remains in teacher preparedness to effectively implement these strategies in classroom settings (Artzt & Armour-Thomas, 1998; Moralı & Korkmaz, 2022).

In line with evolving educational trends, Augmented Reality (AR) has emerged as a transformative tool for enhancing student engagement and performance in mathematics (Angraini & Rahmawati, 2024; İslim et al., 2024; Rahman & Setyaningrum, 2022). AR overlays digital content onto the physical environment, offering immersive, interactive experiences that support deeper learning (Saundarajan et al., 2020). Literature highlights AR's potential to promote metacognitive skill development by increasing student interaction and encouraging learner autonomy (Espinosa-Pinos, Amaluisa Rendón, & Núñez-Torres, 2023). Study by Rahman and Setyaningrum (2021) found that students demonstrated a positive intention to use AR tools, particularly in learning mathematics. Thus, this study proposes the use of AR as a pedagogical approach to support and enhance metacognitive skills in mathematics problem-solving.

## LITERATURE REVIEW

### Metacognitive Skills

Flavell (1979) model of metacognition, introduced in the 1970s, has been instrumental in understanding how individuals regulate their learning through knowledge, experience, and strategy use (Stillman & Mevarech, 2010; Zhang et al.,2024). Metacognition consists of two main components: metacognitive knowledge and metacognitive skills or regulation (Kathayat, 2024). While metacognitive knowledge involves awareness of one's cognitive strengths and weaknesses, metacognitive skills focus on processes such as planning, monitoring, and evaluating tasks (Reyes & Reyes, 2024). These skills, especially metacognitive skills, are crucial in mathematics education as they enable students to reflect on and manage their problem-solving approaches (Restini et al.,2023; Wangguway et al.,2024). By promoting metacognitive awareness and evaluation, students can effectively draw on prior knowledge and assess their strategies (Bakar & Ismail, 2020). Numerous studies have shown a strong link between metacognitive skills and successful mathematical problem-solving (Wang et al.,2021). Through metacognitive skills, students able to carry out their own planning, self-monitoring and self-evaluation when completing a task (Wafubwa & Csíkos, 2021). Therefore, this study will focus specifically on metacognitive skills to help students regulate their learning and enhance their problem-solving abilities (Restini et al., 2023). Metacognitive skills can be described as follows:

1.Planning: A strategy or action plan before tackling a mathematics problem. This includes understanding the problem, identifying the necessary steps, and selecting appropriate methods or formulas to apply (Kathayat 2024)

2.Monitoring: It involves continuously assessing one's progress while solving a problem including checking the accuracy of calculations and ensuring that the chosen methods are leading towards a solution (Mansilla & Díaz 2024)

3.Evaluating: It is a process of reviewing the entire problem-solving after a solution has been reached by assessing the effectiveness of the strategies used and the accuracy of the final answer (Kathayat 2024; Handayani & Naimnule 2023).

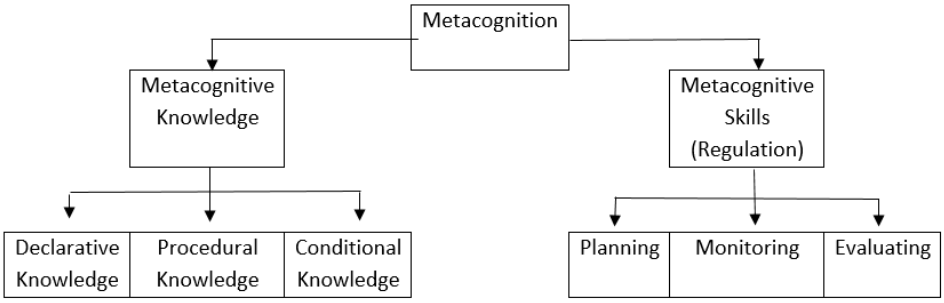


Figure 1
Metacognition by Flavel (1979)

**Metacognitive Skills To Support Mathematics Problem Solving**

Metacognitive skills play a crucial role in enhancing students' understanding and independence in mathematics (Kathayat, 2024). These skills involve awareness of one's cognitive processes, essential for effective problem-solving (Restini et al., 2023). Recent studies show that students demonstrate metacognitive awareness by using prior knowledge and experiences to approach mathematical problems (Catador, 2024; Wangguway et al., 2024). Planning, a core metacognitive skill, helps students organize their thoughts and create structured approaches to solving complex tasks, which is especially evident among high-ability students (Catador, 2024; Restini et al., 2023). Monitoring, another process of metacognitive skills, enables students to self-check, identify errors, and adjust strategies during problem-solving, improving both accuracy and focus (Handayani & Naimnule, 2023; Mansilla & Díaz, 2024). Finally, evaluating allows students to reflect on their problem-solving process, assess outcomes, and refine strategies for future tasks, fostering deeper understanding and continuous improvement (Alkan et al., 2023;Reyes & Reyes,2024). Despite their importance, not all students apply metacognitive skills effectively, particularly those with lower mathematical ability, who often struggle with consistent use of planning, monitoring, and evaluating (Handayani & Naimnule, 2023). This highlights the need for targeted interventions to support the development of metacognitive skills across diverse learner profiles.

**Student Performance in Mathematics Problem-Solving Skills**

Students who actively engage in metacognitive skills, such as planning their approach, monitoring their progress, and evaluating their outcomes, consistently achieve better results in mathematics (Bakar & Ismail, 2020). High-performing students often employ these strategies more effectively, which predicts their academic success (Catador, 2024). This evidence suggests that incorporating metacognitive training in the mathematics curriculum could enhance overall student achievement. This is to enable students to regulate their thinking processes to lead to better problem-solving outcomes (Handayani & Naimnule, 2023). Research consistently demonstrates a strong positive relationship between metacognitive skills and mathematics achievement (Wafubwa & Csíkos, 2021), emphasizing the importance of fostering these skills in educational environments (Catador, 2024). These issues have been discussed in depth and one of the suggested ways to improve students performance in mathematics problem solving is by enhancing their metacognitive skills (Abdullah et al., 2017; Dorji & Subba 2023; Kathyat, 2024).

**AR As Supporting Tools In Mathematics Problem-Solving Skills**

Augmented reality (AR) is increasingly used in education due to its ability to enhance engagement, motivation, and learning experiences (Saundarajan et al., 2020; Suryanti, Arifani, & Sutaji, 2020;). AR in general is a technology that merges real and virtual worlds in real time, often via mobile devices, to enhance perception, interactivity, and learning. In mathematics, AR has shown potential to improve student understanding by providing interactive, real-world applications and dynamic 3D visuals (Özcakir & Çakıroğlu ,2021). Studies suggest AR can enhance performance, motivation, and self-efficacy, yet there is limited research on its role in supporting students' metacognitive skills and problem-solving skills (Saundarajan et al., 2020). Researchers like Kepceoğlu & Serin (2024) and Pedaste et al. (2020) in their systematic reviews recommend exploring how AR can foster metacognitive skills in mathematics education. While AR demonstrates strong potential in enhancing learning experiences, designing effective AR content that aligns with the curriculum, learning objectives, and assisting student learning remains a complex challenge. Most existing studies tend to focus on short-term learning outcomes, with limited attention to long-term retention or knowledge transfer. Furthermore, few studies explicitly examine the metacognitive processes within AR-based learning environments, such as planning, monitoring, and evaluating one's cognitive strategies that purposefully scaffold metacognitive skills represents a promising direction for fostering students' critical thinking and problem-solving in mathematics.Thus, designing AR-based learning modules could be a promising step to help students think critically and solve mathematical problems more effectively.

**Statement of Problem**

While metacognitive skills are vital for mathematical success, however not all students apply these skills effectively. Research indicates that high-ability students consistently engage in planning, monitoring, and evaluation, which enhances their mathematical performance. However, students with lower mathematical abilities often face difficulties in utilizing these skills, leading to suboptimal problem-solving outcomes. This gap in metacognitive skill highlights a critical issue in mathematics education. Without targeted support and explicit instruction, students may lack the ability to regulate their metacognitive skills, ultimately hindering their academic growth. Therefore, there is a pressing need to explore effective interventions that can enhance metacognitive skills and an alternative development across diverse learner. AR has the potential to be used to guide students metacognitive skills in the problem solving process. This study explores from teachers and students' perspectives how AR can be integrated through the problem solving process by assisting students metacognitive skills.

**Research Objective**

The following are the research objectives developed for this study:

1 Determine students' perspectives on how to integrate AR to support metacognitive skills in mathematics problem solving.

2 Determine teachers' perspectives on how to integrate AR to support metacognitive skills in mathematics problem solving.

3 Develop the framework for supporting metacognitive skills by integrating Augmented Reality (AR) in mathematics problems solving

4 Determine the content validity of the framework for supporting metacognitive skills by integrating Augmented Reality (AR) in mathematics problems solving.

## METHOD

This study adopted a descriptive qualitative design and employed purposive sampling, involving five Form 4 students and three experienced Mathematics teachers. The relatively small sample size is justified by the developmental and exploratory nature of the research, which aims to explore the feasibility, usability, and perceived need for an AR-based learning module from both students' and teachers' perspectives. The purpose is not to generalize the findings to a wider population but to gain in-depth insights into participants' experiences, perceptions, and suggestions. These insights will be valuable in designing the framework and guiding future implementation. Ultimately, the findings will contribute to the development of a framework for an AR-integrated Learning Module designed to guide and scaffold students' metacognitive skills in mathematics problem solving.

**Research Flow**

The study starts with a discussion session with students about their perspective on AR as a supporting tools to guide metacognitive skills in mathematics problems. Next, teachers discuss student feedback and suggestions that help develop the module's framework. The developed framework was validated by experts using Content Validator Index (CVI) (Yusoff,2019).

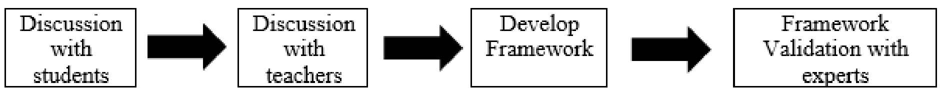


Figure 2
Research flow

**Discussion with students'**

To achieve research objective 1, a discussion among form 4 student were conducted. The five students were selected based on their willingness to participate in the study- and their character that were talkative and responsive in the classroom. In the discussion, students were given 5 math problem solving question under the topic Quadratic Functions and Equations in One Variable. The students were asked to read and understand the question and gave their feedback on how researchers can inject the AR function into the problem solving process to enhance their metacognitive skills.

This discussion session gives students the opportunity to express the type of support they need to successfully solve a series of mathematics problem. The students were asked about their plans and strategies to solve mathematics problems. Their opinions and difficulties in solving the problems were also discussed. This discussion will help on the development of the framework about the content of AR such as where to put visual images, video, audios and additional texts in the problem.

**Discussion with Teachers**

After the discussion with students, the researcher conducted a one-to-one session with three teachers about student's responses from the initial interview. This is to add more input to the students' responses. The three teachers had around 10 years' experience in teaching secondary school mathematics. The teachers gave their opinion on which part of the problems and problem- solving process required image trackers to assist students in supporting students' metacognitive skills for successful mathematics problem solving.

**Development of Framework**

After the interviews, the recorded statements were transcribed and coded according to the three metacognitive skills which are planning, monitoring, and evaluating. In the coding process, phrases or sentences that express an idea or suggestion were designated to specific categories of metacognitive skills. The indicators for the coding are based on Metacognition Flavell Model 1979 focusing on metacognitive skills or regulation only. For planning, the indicators are any statement that express, analysing the problem before beginning the problem solving process, identify relevant formulas, concept and strategies. Other than that, statement that break down (Handayani & Naimnule, 2023) information for example underline the information from the question given. Meanwhile, for monitoring, the indicators are any statement that express checking the chosen strategy (Mansilla & Díaz, 2024) is working for example a student mention "I need examples with step-by-step guidance solution". Other than that, any statement from teachers or students related to other formulas (Alkan et al., 2023).

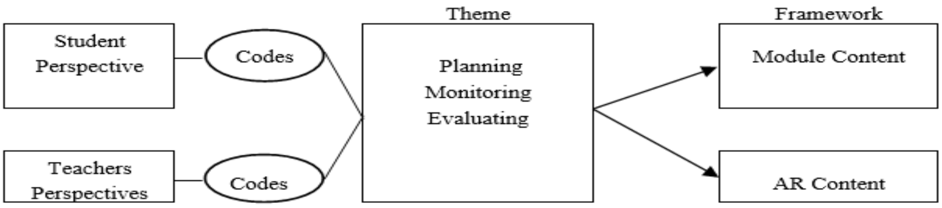


Figure 3
Coding process

For example, "I need a hint that is related to the area formula and Quadratic Functions and Equations in One Variable". Finally, for evaluating, the indicators are any statement that mention on checking solution such as providing details answer scheme, assessing the strategy efficiency and identifying the final answer (Kathayat, 2024). It was decided that to develop an AR integrated module, two things need to be considered, the content of the module and the AR object to be integrated since both will make up a complete AR integrated module, so the framework itself will still highlight these two components

### Validation Framework from an Experts

The next step in the validation process involves expert validation using the Content Validity Index (CVI), a method to measure how well items represent the intended construct. This study follows Yusoff (2019) six-step content validation process which is preparing the validation form, selecting expert panel, conducting content validation, reviewing the framework, scoring the item and calculating CVI framework.

## FINDINGS

### Student Perspectives to Integrate AR in Mathematics Problem Solving to Support Student Metacognitive Skills

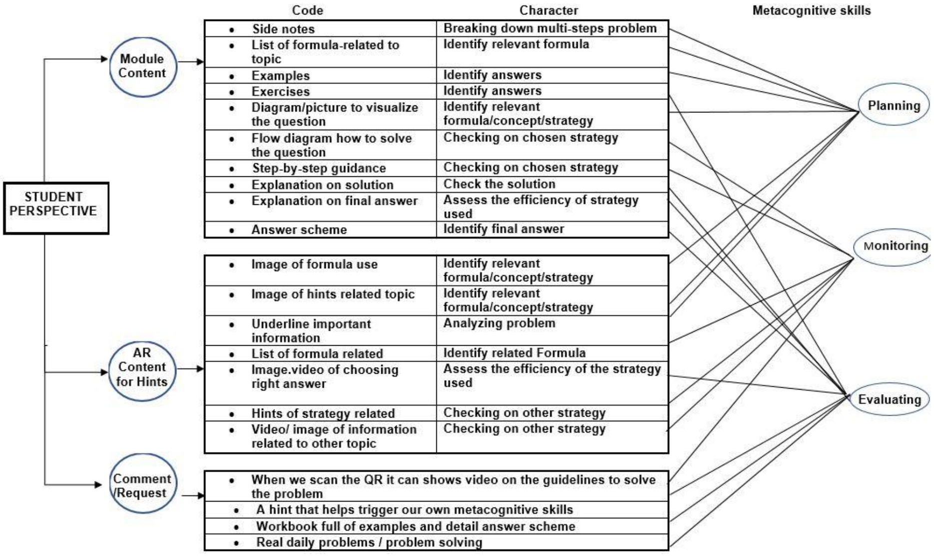


Figure 4
Student perspectives on integration of AR

For Planning, students suggested the inclusion of side notes, formula lists, worked examples, and visual aids such as diagrams or pictures to enhance conceptual understanding. In the Monitoring phase, students recommended flowcharts and structured guidance tables to support their step-by-step problem-solving processes. For Evaluation, they emphasized the need for practice exercises, solution explanations, and opportunities to review and cross-check answers with a provided answer scheme to deepen comprehension. Regarding the augmented reality (AR) content, students proposed that the Planning section should include AR hints featuring relevant formula images, visual diagrams related to the questions, underlined key information, and a compiled list of formulas. In the Monitoring stage, they recommended AR-integrated strategies delivered through videos or images that connect with related mathematical topics. QR codes linked to video guides were also suggested to provide scaffolded problem-solving support, encouraging active engagement with metacognitive strategies.

For Evaluation, students highlighted the importance of detailed answer schemes and requested hints in the form of images or video explanations to help them make informed decisions when selecting answers. Additionally, they expressed interest in incorporating real-life problem-based exercises to enhance the relevance and applicability of mathematical learning.

**Teacher's Perspectives to Integrate AR in Mathematics Problem Solving to Support Student Metacognitive Skills**

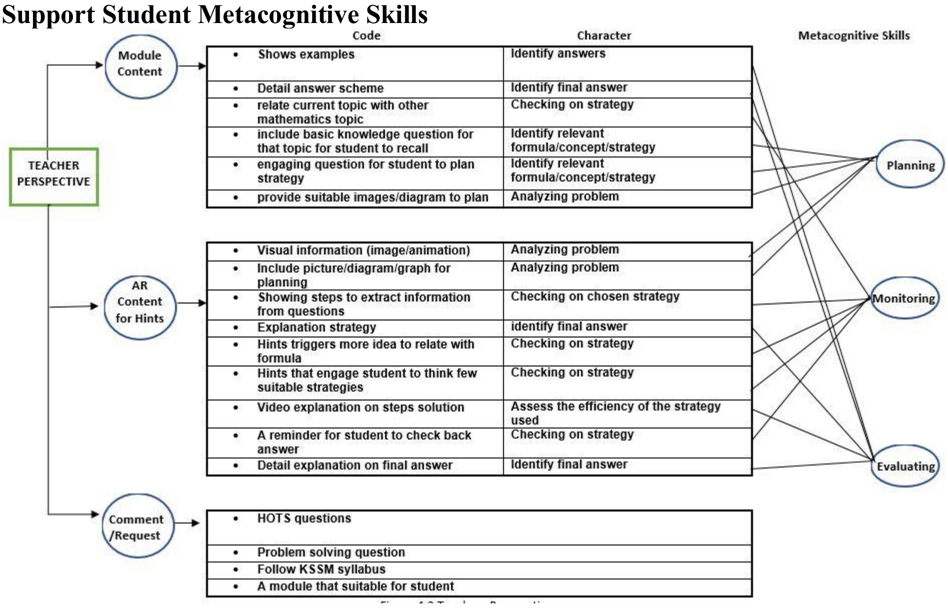


Figure 5
Teacher Perspective on Integration of AR

In terms of content design, the teachers recommended including appropriate images and diagrams to support Planning, alongside basic knowledge questions that activate prior learning and stimulate strategic thinking. For Monitoring, they suggested incorporating questions that link the topic to other mathematical areas, encouraging students to explore diverse problem-solving approaches. Regarding Evaluation, the inclusion of worked examples and detailed answer schemes was seen as critical for enabling students to assess their own solutions independently. For AR integration, the teachers preferred visual elements such as animations, graphs, example-based images, and diagrams to facilitate planning. For monitoring, AR hints should guide students in connecting current content with prior knowledge, particularly by relating formulas across topics. Additionally, AR features should prompt students to extract key information from problems and consider multiple solution strategies. The use of video explanations was also recommended to further scaffold students' understanding during the evaluation phase. Overall, the teachers' insights highlight the potential of AR to serve as a metacognitive scaffold when thoughtfully aligned with instructional objectives

**Designing Framework For Supporting Secondary School Students' Metacognitive Skills By Integrating Augmented Reality (AR) In Mathematics Problem Solving.**

This framework serves as a foundational step in developing a comprehensive learning module and comprises two core components: the Learning Module and the AR content. The Learning Module provides the main instructional structure, whereas the AR component offers interactive and real-time support aimed at reinforcing students' metacognitive processes. While previous studies on AR in mathematics education have primarily emphasized its role in enhancing students' motivation and academic performance, this research introduces a novel perspective by employing AR as a scaffolding tool to guide students in activating and applying their own metacognitive skills. Through this integration, students are encouraged to plan, monitor, and evaluate their learning as they engage with mathematical concepts. The framework is systematically aligned with the three key phases of metacognitive skills, planning, monitoring, and evaluating. Each of which is embedded within both the Learning Module and the AR component to promote deeper, self-regulated mathematical learning. This framework serves as a foundational step in the development of a comprehensive learning module and consists of two core components: the Learning Module and the AR content. The Learning Module represents the main instructional content, while the AR component is designed to provide interactive, real-time support to reinforce metacognitive skills processes.. The framework is aligned with three key metacognitive phases which are planning, monitoring, and evaluating that each embedded into both the Learning Module and AR content.

**Learning Module Content**

Planning phase is to supports students in organizing their approach to problem-solving. The Learning Module includes concise revision notes and a list of essential formulas not only for the current topic (e.g., quadratic functions and equations in one variable) but also for related topics. The inclusion of diagrams or images helps students visualize mathematical problems, promoting analytical thinking and aiding comprehension. These elements aim to activate prior knowledge and help students plan more effectively. Meanwhile, monitoring phase is to facilitate self-monitoring, the module provides worked examples with clear, step-by-step solutions. This allows students to compare their strategies and track their problem-solving progress. The inclusion of detailed answer schemes enables students to identify discrepancies in their methods and reflect on the logic of their solutions, thus encouraging self-correction and adjustment of strategies. Lastly, the evaluating phase to focuses on enabling students to assess their answers critically. The Learning Module must include final solution explanations, helping students understand the rationale behind correct answers. Through comparison and reflection, students are encouraged to analyse the effectiveness of their strategies and identify areas for improvement.

**AR Content**

The integrated framework as shown in Figure 6 with intellectual property number LY2024J08992, Augmented Reality (AR) plays a crucial role in enhancing students' metacognitive skills throughout the problem-solving process. During the planning phase, AR is utilized to help students strategize more effectively by presenting hints through videos, animations, and visual cues that highlight key information and relevant formulas. These features support the activation of prior knowledge, assist in identifying appropriate strategies, and improve students' ability to visualize mathematical problems. In the monitoring phase, AR content provides contextual hints delivered via images or video that encourage students to draw connections between the current problem and other related mathematical topics. This fosters flexible thinking and supports deeper metacognitive skills engagement by demonstrating how various mathematical concepts can be integrated into problem-solving. Finally, in the evaluating phase, AR supports critical reflection by offering step-by-step guidance through animations and video explanations. These resources enable students to assess their own reasoning, compare it with correct solutions, and recognize errors in their approaches. Collectively, the AR-enhanced elements guide students in developing self-regulated learning habits, strengthening their metacognitive awareness, and promoting a more thoughtful and autonomous approach to mathematics.

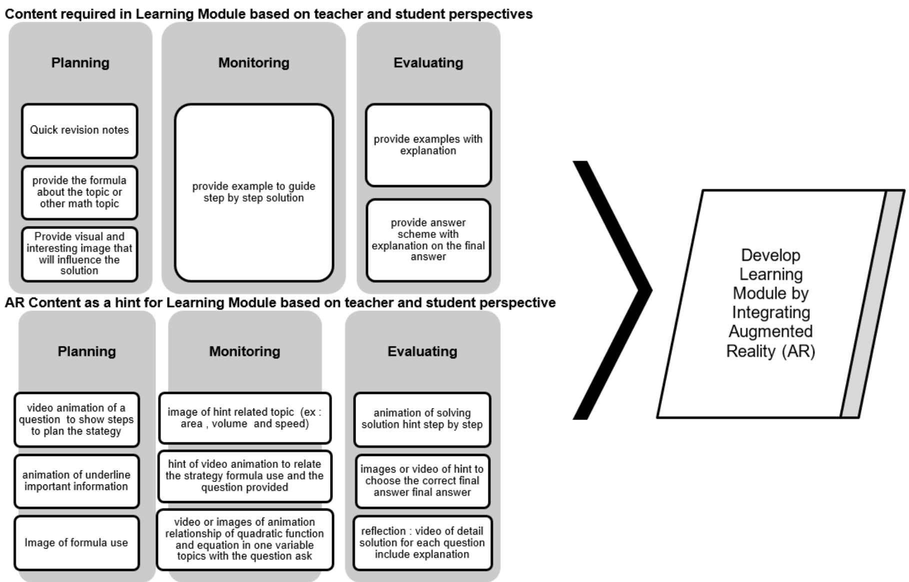


Figure 6
Framework

**Content Validity of Framework**

As refer to Table 1, it shows average CVI scores. Expert number 6 did not agree on one item in planning meanwhile, other experts agreed on all item in the framework for planning, monitoring and evaluating the metacognitive skills for the framework. The average I-CVI score for planning are 0.98, monitoring 1.00 and evaluating 1.00. Meanwhile, the average UA recorded for planning is 0.86, monitoring is 1.00 and evaluating is 1.00. For the item that scored, 1.00 means that all expert agreed that the items align with the framework and the feedback from student and teachers. The score S-CVI/Ave is 0.99 and S-CVI/UA is 0.96. Thus, this framework meet the requirement of Content Validty index which need to be at least the 0.78 or higher for I-CVI and 0.90 or higher for S-CVI to considered as good content (Yusoff, M. S. B.,2019).

Table 1
Average score

| | Expert | | | | | | | | Ave | Ave |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | EIA | I-CVI | UA |
| Planning | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.86 | 1.00 | 6.00 | 0.98 | 0.86 |
| Monitoring | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 7.00 | 1.00 | 1.00 |
| Evaluating | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 7.00 | 1.00 | 1.00 |
| Average Proportional Relevance | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.95 | 1.00 | | | |
| S-CVI/Ave | | | | | | | | | 0.99 | |
| S-CVI/UA | | | | | | | | | | 0.96 |

**DISCUSSION**

Student performance in mathematics is influenced by a variety of factors, including teacher support, student attitudes, self-regulated learning, and contextual elements (Dorji & Suba, 2023; Ngan et al.,2019; Restini et al., 2023). This study conducts a discussion session with both students and teachers to develop an AR based framework. This framework presents a promising approach to integrating technology into education, with a particular focus on enhancing students' metacognitive skills, which are essential for effective problem-solving (Abdullah et al.,2017; Bakar & Ismail,2020; Shodikin et al.,2022). Such an approach is vital in supporting both teachers and students in improving student's metacognitive skills, thereby fostering better performance in mathematics.

There are three process of metacognitive skills that been discussed which are planning, monitoring and evaluating (Kathayat,2024). Based on discussion, teachers and students suggest that they need side notes and formula in the planning process that engage them to analyse the information. Example for planning could be "underline the important information" or "write the quadratic equation from the question". This is also mentioned by Handayani & Naimnule (2023) that planning is a strategy or action plan prior to solving a mathematics problem involving comprehending the problem, determining the required steps, and choosing the correct methods or formulas to use. Related formulas should be provided in the learning module to enable their metacognitive skills to plan using the knowledge they have with the current problem and information they have (Catador,2024). This visual image or animation used in AR helps to enhance student metacognitive skills by exploring the hints given to plan a strategy with the knowledge they have to solve problems (Angraini & Rahmawati, 2024). In addition, AR helps to visualize the real world which can assist in the planning process (Dorji&Suba , 2023; Pedaste et al., 2020; Carlos-Chullo et al., 2020).

The process of monitoring involves checking that the chosen formula and strategy is relevant and also applying the information in planning and relating it to other information or other mathematical knowledge that is suitable (Wafubwa & Csíkos, 2021). The AR hint suggested in the framework support metacognitive skills by providing animation or videos to simulate the process. The monitoring in this framework use AR to provide hints on the relationship between the planning and other mathematical knowledge that may be hidden to complete the task. The hint can be in the form of a video or image of information. With the support of AR it can help to improve metacognitive skills through structured judgment questions, enhancing students' ability to monitor their learning processes when solving a problem (Mansilla et al., 2024; Moralı & Korkmaz, 2022).

The teachers and students expects that evaluation is to guide the student to assess whether the strategy used was efficient or if another approach could have been better (Handayani & Naimnule, 2023) by providing an answer scheme with detailed explanation. This involves the student evaluating the entire problem-solving process after reaching a solution, by assessing the effectiveness of the strategies employed and the correctness of the final answer (Kathayat, 2024). The benefits of AR in this framework enables students to explore content in new learning experiences that were previously not possible (Majid et al., 2024; Rahman & Setyaningrum, 2022). For instance, video explanation of minimum and maximum point of a graph, through 2D models where student able to play around the values of variable to see the impact on graph. Engaging with this kind of interactive content (details solution) encourages students motivation to think critically about how they are engaging with the material for better understanding to solve future problems (Pinos et al., 2023).

Overall, this framework serves as a guide for teachers and students to develop AR tools that can support students metacognitive skills in mathematics. Research has shown that AR effectively enhances students' mathematics performance (Mansilla &Diaz, 2024). Moreover, modern classrooms are increasingly integrating digital tools and technology to improve students' understanding, motivation, and engagement (Angraini& Rahmawati,2024; Rahman & Setyaningrum, 2022; Suryanti et al.,2020). AR has also been proven to boost student performance, motivation and interest to learn mathematics (Kepceoğlu & Serin, 2024; Pedaste et al.,2020; Rahman & Setyaningrum, 2021). This framework holds promise in enhancing metacognitive skills, addressing research gaps to technological accessibility and the need for teacher to implement guidelines in mathematics education. The content of the framework has been validated using content validity methods. While the acceptable cut-off for content validity index (CVI) values typically requires 0.78 or higher for I-CVI and 0.90 or higher for S-CVI (Yusoff, M. S. B.,2019). This study achieved an I-CVI of 0.99. This indicats that 99% of the framework's content aligns with the needs of both students and teachers. Although AR shows potential for improving metacognitive skills, challenges such as technological accessibility persist. The results align with prior research highlighting AR's potential to enhance engagement and conceptual understanding, while extending the conversation by demonstrating its capacity to scaffold students' metacognitive skills. However, this study is not without limitations. The use of a small purposive sample limits the generalizability of the findings, and the range of ideas and perspectives informing the development of the learning module and AR content was necessarily constrained. Nevertheless, the study provides meaningful insights into the design and development of AR-integrated learning modules that effectively scaffold students' metacognitive skills. Ultimately, the proposed framework serves as a comprehensive and practical guide for teachers and students to enhance metacognitive skills in mathematics problem solving through the purposeful integration of AR in mathematics learning.

## CONCLUSION

In conclusion, the integrated framework illustrated in Figure 6 aims to enhance students' metacognitive skills by combining structured learning through a problem-solving module with interactive support via Augmented Reality (AR). The Learning Module fosters deliberate practice in metacognitive strategies, while the AR content offers timely, targeted assistance across the planning, monitoring, and evaluation phases of problem-solving. Together, these components promote self-regulated learning, enabling students to engage with mathematical problems more independently, confidently, and reflectively. Future research could explore the application of this framework across several mathematical domains, given its potential to foster metacognitive development through immersive technology. Moreover, this approach may empower students to take greater ownership of their learning, thereby enhancing the depth and relevance of their educational experiences. As students increasingly rely on their metacognitive skills such as planning, monitoring and evaluating so they can transition into more autonomous learners. Over time, the integration of AR can reduce their dependence on teacher guidance, fostering greater academic independence and potentially leading to improved performance in mathematics.

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