Developing MoAR-Integrated Printed Learning Modules to Improve Mathematical Problem-Solving Abilities in Geometry Learning

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***Abstract*—This research develops an interactive printed learning module with Augmented Reality (AR), adopting the design research methodology and ADDIE model. The primary focus is to improve students' mathematical problem-solving abilities by integrating AR technology to contextualize abstract concepts in real-life scenarios in a printed module on geometry learning. This study presents a MoAR-integrated printed learning module that combine meticulously planned educational materials, engaging activities, evaluation, 9E learning cycle syntax, problem-solving steps, and QR-code markers. The module seamlessly integrates with the MoAR apps, further the learning experience. The module's validity is confirmed by a panel of seven experts, yielding a high V-coefficient of 0.92. The implementation was done at Public Junior High School SMPN 2 Mantup, involving 68 students in experimental and control classes. Practicality and effectiveness analysis measured through questionnaires and N-gain score comparison indicate that the developed learning module is practical and led to a higher increase in problem-solving abilities in the experimental class compared to the control class. This study represents an innovation in mathematics learning by integrating AR technology into a comprehensive printed learning module designed for independent use. It is recommended for further researchers to include the development of more specific AR content for particular mathematical topics and analyzing the long-term impact of AR use on improving mathematical abilities.**

***Keywords*—learning module, problem solving, Augmented Reality (AR)**

I. Introduction

The emergence of the Industry 4.0 revolution has significantly influenced the progress of education through the integration of sophisticated technologies in the teaching and learning process [1]. In the 21st century, individuals are required to possess various skills, including problem-solving and critical thinking, particularly in the field of mathematics [2]. Proficiency in mathematical problem-solving is considered a fundamental ability necessary for real-life applications and future careers [3].

Previous research indicates that students still encounter difficulties in solving problems [4, 5]. Based on the observations conducted, it was found that teachers and students use government-published textbooks in their learning process. However, these textbooks do not yet include precise learning steps that students can use for independent study. Additionally, traditional printed textbooks from the government have limitations in visualizing geometric concepts, which are essential for a deeper understanding. Visual representations enable students to perceive mathematical objects from different perspectives and manipulate them [6, 7]. Therefore, printed textbooks should contain clear learning steps to accommodate independent learning and provide additional support for visualization [8].

In facing the COVID-19 pandemic and the widespread use of online learning, there has been a shift in the learning paradigm. Traditional classroom-centered education with teacher guidance has transformed into a self-directed learning approach which forces students learn and evaluate independently [9]. Consequently, there is a demand for a learning module that serves as an instructional tool to facilitate independent learning, minimizing the reliance on external assistance [10]. A learning module comprises comprehensive, systematic, and well-planned educational materials, learning activities, exercises, and assessments. The use of modules in education has proven to be an effective approach to enhancing mathematical problem-solving ability [11–14].

Solving problems requires students to apply mathematical knowledge in real-life contexts [15]. Therefore, students need to have competent knowledge to solve problems independently. To enhance the comprehension of complex mathematical objects, especially in geometry, incorporating multi-dimensional visualizations is vital [16–18]. With the advancements in technology, learning modules have been integrated in various ways to incorporate digital information [19, 20]. The addition of information can be achieved by transforming the learning module into an e-module, exclusively accessed digitally [1, 21, 22]. However, it is important to note that prolonged use of electronic learning media might lead to symptoms like eye pain, headaches, and dry eye sensations [23]. Therefore, exploring alternatives that seamlessly combine digital information with paper-based modules is crucial. Augmented Reality (AR) emerges as a promising solution.

AR is a technology that enhances real-world objects with digital information [8, 24, 25]. Synthetic data such as graphics, animations, texts, sounds, and videos can be incorporated to enhance the environment through the utilization of cameras and screens [26–28]. AR has been increasingly used in educational research to improve learning media. In mathematics education, the use of AR is often limited to providing visual representations of mathematical objects. For example, Ahmad and Junaini [28] developed the *PrismAR* app, which displayed 3D models of prisms and their parts, but it did not include any instructional content. In a similar vein, the research conducted by Fortuna *et al.* [29] on teaching an engineering mechanics course with AR focused mainly on visual representations of objects. Mayashofa and Nashiroh [30] also employed AR in the same manner, utilizing AR to enhance the promotion of a tourist site in Indonesia.

The potential of AR can be fully harnessed in addressing the paradigm shift in education by implementing self-directed learning and integrating it into a learning module. This approach is exemplified in the study by Budi *et al.* [31] which integrated AR and video into an e-module, demonstrating the potential of AR as a learning support tool. Furthermore, the research by Nadzri *et al.* also revealed the effectiveness of AR-based learning modules in mathematics education, specifically in geometry [32]. However, existing research has not specifically aimed at improving mathematical problem-solving abilities.

Mathematical problem-solving ability requires training in problem-solving steps within a specific learning model syntax [33]. Unfortunately, the development of learning modules integrating AR technology often lacks a clear learning model syntax, leading students to face a heap of materials without knowing the sequence and how to study them [31, 34]. Hence, it is essential to develop an AR-based interactive printed learning module that includes a learning model syntax and educational content, which encompasses material designed to train students in the steps of problem-solving, evaluative procedures, and seamlessly integrate technology to augment the visualization of geometric objects through AR. All these elements are specifically aimed at improving mathematical problem-solving abilities. The completeness of these aspects in the AR-based interactive printed learning module represents the novelty of this research.

The objective of this research is to develop and evaluate an AR-based interactive printed learning module and a QR-Code scanner application with multimedia content display on Android smartphones, called MoAR. Both products produced are intended to create mathematics learning modules that retain their paper-based nature while incorporating multimedia through AR. Based on the above explanation, the research questions are formulated as follows:

1) How can the MoAR-integrated printed learning module be developed to improve mathematical problem-solving abilities in geometry learning?

These main research questions are further broken down into the following sub-questions:

a. How is the validity of the MoAR-integrated printed learning module to improve mathematical problem-solving abilities in geometry learning?
b. How is the practicality of the MoAR-integrated printed learning module to improve mathematical problem-solving abilities in geometry learning?
c. How is the effectiveness of the MoAR-integrated printed learning module to improve mathematical problem-solving abilities in geometry learning?

II. Methods

This study employs design research methodology to create an innovative learning ecosystem for local learning theories and supported learning forms [35]. The concrete implementation involves three phases: Preparation, Experimentation, and Retrospective Analysis. To ensure detailed execution, the ADDIE model with Analyze, Design, Develop, Implement, and Evaluate phases is chosen [36]. ADDIE's framework effectively handles complex scenarios and aids in creating educational materials. Fig. 1 shows the research workflows based on the ADDIE model.

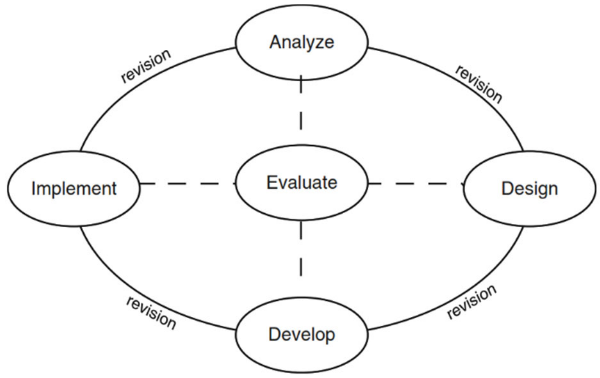

Fig. 1. The research workflows based on the ADDIE model.

The ADDIE model development consists of five phases. The first is the 'analyze phase'; this phase involves preliminary research and field exploration. The second is the 'design phase,' where the components of the developed product, such as material, layout, and module usage system, are determined based on findings from the analyze phase. The third is the 'develop phase' which involves the creation of a prototype. The fourth is the 'implement phase,' entailing field testing. The fifth is the 'evaluate phase' which assesses the quality of the developed product both before and after implementation [36]. In this study, the report of the evaluation phase is presented as the final sequence in the ADDIE model, detailing evaluations of validity, practicality, and effectiveness. The validity evaluation is embedded in the development phase after the prototype is formed. Practicality evaluation is embedded in the implementation phase after learning using the AR-based interactive printed learning module in the experimental class. Lastly, the effectiveness evaluation is embedded in the implementation phase after the entire learning process is completed in both the control and experimental classes.

The study employed non-probability purposive sampling to select participants based on the researchers' judgment [37]. The research involved ninth-grade students from Public Junior High School SMPN 2 Mantup. Two out of eight ninth-grade classes (68 students in total) participated, divided into an experimental and a control class, each with 34 students. The validity test was conducted by expert validators comprising four lecturers, two from the departments of mathematics and science education, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Sunan Ampel (UINSA), and two from the department of mathematics education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang (UNNES), along with three Junior High school (JH) mathematics teachers holding a master's in mathematics education.

Table 1 presents a list of validators who will assess the validity of the printed learning module and the MoAR apps. Each validator will evaluate aspects of content quality, design presentation, and quality to support learning, with a dedicated comment section for each.

Table 1. List of validators

No.	Validator	Expertise	Position
1	Validator 1	Media in Mathematics Education	Mathematics Education UINSA Lecturer
2	Validator 2	Mathematics Education	Mathematics Education UINSA Lecturer
3	Validator 3	Mathematics Learning Process	Mathematics Education UNNES Lecturer
4	Validator 4	ICT in Mathematics Education	Mathematics Education UNNES Lecturer
5	Validator 5	Mathematics Education	Mathematics Teacher JH
6	Validator 6	Mathematics Education	Mathematics Teacher JH
7	Validator 7	Mathematics Education	Mathematics Teacher JH

The practicality of the MoAR-integrated printed learning module was evaluated by using 21 items in content quality, user interaction, and student motivation, assessed by the experimental class students after the learning session. Effectiveness was gauged through a post-learning written test, also in the experimental class. The test instrument was systematically developed, aligning with curriculum goals and incorporating non-routine questions, while ensuring validity and reliability. For effectiveness, both pretests and posttests, sharing difficulty level and indicators, were used to assess mathematical problem-solving abilities, as outlined in Tables 2 and 3.

Table 2. Indicators of mathematical problem-solving ability [15]

No.	indicators
1.	Build new knowledge through problem-solving
2.	Solve problems that arise in mathematics and other contexts
3.	Apply and adapt a variety of appropriate strategies to solve problems
4.	Monitor and reflect on the process of mathematical problem-solving

Table 3. Indicators of pretest and posttest

No.	Topic	Question Indicator	Mathematical Problem-Solving Ability Indicators
1	Congruence of plane figures	Identification and application of congruence concepts in plane figures for real-world calculations.	1,2
2	Congruence of two triangles	Proof of triangle congruence using properties of lines and angles.	1,4
3	Similarity of plane figures	Application of similarity principles in plane figures to solve problems related to ratios and scales.	2,3
4	Similarity of two triangles	Application of triangle similarity concepts for solving real-world problems involving size comparisons.	2,3
5	Similarity of two triangles (indirect distance measurement)	Application of triangle similarity principles in indirect distance measurement and solving geometric problems.	2,4

The test instrument's validity and reliability were evaluated on a pilot class of 38 students, focusing on the posttest due to time and resource constraints, ensuring it matched the pretest in indicators and difficulty. The validity test was analyzed by using the product-moment correlation formula with a significance level (α) of 0.05, resulting in r_{table} value of 0.339. If the calculated correlation coefficient (r_{number}) is greater than or equal to the critical value (r_{table}), the item is considered statistically significant, indicating its validity and suitability for use. The validity analysis results, obtained through the product-moment correlation formula, can be found in Table 4.

Table 4. The results of the test instrument's validity analysis

Item Test	1	2	3	4	5
$\sum score\ (N = 38)$	223	216	244	237	181
r_{number}	0.645	0.817	0.644	0.540	0.619
r_{table}			0.339		
Category	**Valid**	**Valid**	**Valid**	**Valid**	**Valid**

Next, to assess the reliability, Cronbach's Alpha coefficient (r_{11}) was calculated and compared to the critical value (r_{table}). Based on the test conducted in the pilot class with a sample size (N) of 38, the obtained r_{11} value was 0.407 with a significance level (α) of 0.05, it was found that $r_{11} = 0.407 > r_{table} = 0.339$, indicating that the test instrument is deemed reliable.

Data from validation sheets were tabulated and analyzed in Microsoft Excel. The validity level was determined V-coefficient by using the formula:

$$V = \frac{\sum s}{n(c-1)} \tag{1}$$

Description:
V = Validity coefficient.
s = Difference between the number of validators and the lowest validity category.
n = Number of validators.
c = Number of available validity categories.

Then, to determine the validity level, reference was made to Table 5, which outlines the validity categories.

Table 5. Validity categories [38]

Percentage of Validity Score	Predicate
$0.75 < V \leq 1.0$	Valid
$0.4 < V \leq 0.75$	Less valid
$0 < V \leq 0.4$	Not valid

Descriptive analysis was also conducted on the usability questionnaire results to ascertain practicality from student users' perspectives. To determine the percentage of practicality, the following formula was used:

$$\%NKP = \frac{PS}{PM} \times 100\% \tag{2}$$

Description:
$\%NKP$ = Percentage of Practicality Score
PS = Practicality Score Obtained
PM = Maximum of Practicality Score

Then, the level of practicality is determined based in the provided criteria, as outlined in Table 6, which presents practicality categories.

Table 6. Practicality categories

Percentage of Practicality Score	Predicate
$75\% \leq \%NKP \leq 100\%$	Very practical
$50\% \leq \%NKP < 75\%$	Practical
$25\% \leq \%NKP < 50\%$	Less practical
$0\% \leq \%NKP < 25\%$	Not practical

For assessing the module's effectiveness, inferential statistical tests were performed on quantitative data from pretest-posttest results using a quasi-experimental design, specifically the Nonequivalent Control Group design. This involved random assignment of experimental and control classes, treating the experimental class [37]. Pretest and posttest results were analyzed with N-Gain and comparative tests by using RStudio 2023.12.0 Build 369.

III. Result and Discussion

In this research, the ADDIE development model, which comprises five phases, serves as a comprehensive framework and reference point for guiding product development processes, as outlined in the following.

A. Analyze Phase

In the preliminary study at Public Junior High School SMPN 2 Mantup, based on the pretest, both the experimental and control classes faced challenges with geometry problems related to plane figures in the context of the real world. Approximately 70% of students encountered difficulties in applying mathematical knowledge to real-world contexts, as evident from their problem-solving test performance. The learning environment emphasized structured problems and formulaic solutions, limiting their capacity to tackle non-routine problems that demand deeper analysis—a crucial aspect for improving mathematical problem-solving abilities [39].

The utilization of government-published textbooks lacking clear learning steps renders students reliant on teacher instructions and limited to completing assigned homework. Consequently, clear learning steps are essential to ensure the developed learning module is usable independently. Therefore, the 9E Learning Cycle is chosen for the entire learning process. The 9E Learning Cycle serves as the foundational instructional model for the MoAR-integrated printed learning module. This cycle promotes higher technical knowledge, skills, and advanced learning outcomes [40]. The 9E Learning Cycle model is intended to enhance students' competence and skills [40, 41]. The use of technology is well-supported and accommodated in the 9E Learning Cycle model [40]. Hence, this instructional model is suitable and mutually supportive when integrated into MoAR-integrated printed learning modules.

Despite the prevalence of Android smartphones among students and teachers, technology integration remains limited. The COVID-19 pandemic accelerated the use of online learning via smartphones, despite persistent internet signal issues. Communication platforms like WhatsApp, Google Classroom, and Edmodo serve their purposes but face challenges due to inconsistent internet signal strength. This situation led to students congregating in specific areas for better internet access. Based on interviews with students, it was observed that they are more accustomed to using smartphones with an average screen size of 6 inches for all their online activities. Consequently, the utilization of digital learning modules might necessitate prolonged reading on a narrow screen.

The findings emphasize the necessity of interactive printed learning modules and MoAR apps designed to ensure an optimal learning experience for students encountering challenges related to internet connectivity and screen size. A needs analysis identified the foundation for developing the interactive printed learning module and MoAR apps, involving five criteria detailed in Table 7.

Table 7. Results of needs analysis

Criteria	Explanation
Content Quality	The learning content must align with curriculum subjects and objectives, addressing students' needs in practicing mathematical problem-solving abilities.
Design Presentation	Both the printed learning module and MoAR should engage learners with illustrative visuals that enhance the teaching and learning experience.
Quality in Supporting Learning	The developed MoAR-integrated printed learning module should provide clear self-directed learning steps that are easily operable offline.
User Interaction	Usage of the AR-based interactive printed learning module should be intuitive for both teachers and students throughout the teaching and learning process.
Student Motivation	The AR-based interactive printed learning module should integrate visuals and activities that sustain student motivation during independent and classroom learning.

B. Design Phase

The design phase involves defining learning materials, structuring layout and content, specifying usage methods and user interface, establishing learning steps, and outlining the content of the problem-solving steps.

Learning materials: The design phase involves selecting curriculum-aligned learning materials. Grade IX geometry content focuses on congruence and similarity, forming the core topics in the learning module. These topics are divided into four subtopics: 1) Congruence of plane figures, 2) Congruence of two triangles, 3) Similarity of plane figures, and 4) Similarity of two triangles.

Layout and content: The learning module adopts a horizontal layout with a vibrant color to create a refreshing ambiance (Fig. 2). Each page is divided into two columns for flexibility in integrating illustrations and markers.

Meanwhile, the layout of the MoAR is designed to have a default portrait display on Android smartphones. The MoAR background is also aligned with the printed learning module.

The content of the printed learning module and MoAR can be seen in Figs. 2 and 3, consisting of texts, figures, illustrations, and markers in the form of QR codes. On the other hand, MoAR will display videos and 2D animations related to the current learning material, corresponding to the scanned QR code.

Fig. 2. Main cover of the printed learning module.

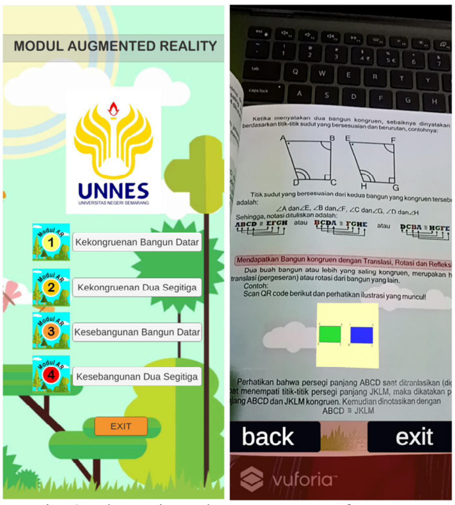

Fig. 3. The main and scanner page of MoAR.

Usage and User Interface. The MoAR-integrated printed learning module is designed as user-friendly as possible. Students using the print version can directly write answers on it (Fig. 4). Formative evaluations for subtopics and a summative evaluation are included. An answer key aids independent assessment. QR codes on the module can be scanned with the MoAR Android app.

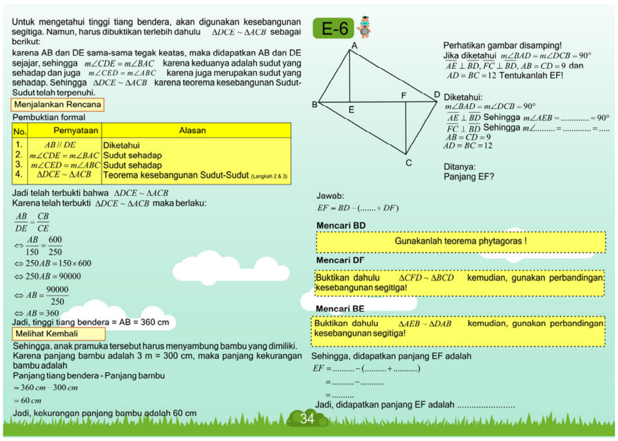

Fig. 4. Learning activities in the printed learning module.

MoAR's user interface aligns with specific subtopics, featuring four buttons for each sub-topic scanning and an exit button (Fig. 3). Choosing a subtopic button promptly activates the smartphone's camera, with options to exit or return to the main menu.

Learning steps: Each phase of the 9E learning cycle is assigned a code from E-1 to E-9 in the printed learning module. The details of the 9E learning cycle contained in the MoAR-integrated printed learning module can be seen in Table 8.

Table 8. Details of the 9E learning cycle in the MoAR-integrated interactive printed learning module

Phases	Explanation
E-1: Elicitation	Practical applications, real-life significance, videos, and animations presented with MoAR scanning to stimulate interest.
E-2: Engagement	Exploration of students' prior knowledge relevant to the subject matter to be used in the learning process.
E-3 and E-4: Exploration and Explanation	Simultaneous presentation due to interdependent learning activities and explanations.
E-5: Echo	Summarization and provision of problem examples encompassing concepts and real-life issues.
E-6: Elaboration	Offering challenging problems to assess contextual understanding and mathematical problem-solving abilities.
E-7: Evaluation	Presenting five questions to assess conceptual understanding and mathematical problem-solving abilities.
E-8: Emendation	Providing columns for students to note difficulties or unclear material delivery during module use.
E-9: E-Search	Using MoAR to access animations and videos.

The content of the problem-solving steps: The content of the problem-solving steps is explicitly outlined in the learning module including the explicit presentation of the problem-solving steps proposed by Polya [42], which are: 1) Understanding the problem; 2) Devising a plan; 3) Carrying out the plan; and 4) Looking back.

The training of mathematical problem-solving abilities is also described in detail through the solution of example problems, specifying the stages of problem-solving involved in reaching a solution. Furthermore, in the developed learning module, Fig. 5 illustrates the application of Polya's problem-solving steps. These steps are demonstrated in solving example problems, where solutions are provided in full detail. Additionally, other problems are presented to students with certain parts left blank. Students are guided to complete them with the assistance of cues and directed to follow Polya's problem-solving steps. The selection of problems in E6 and E7 is also based on situations that require reasoning skills.

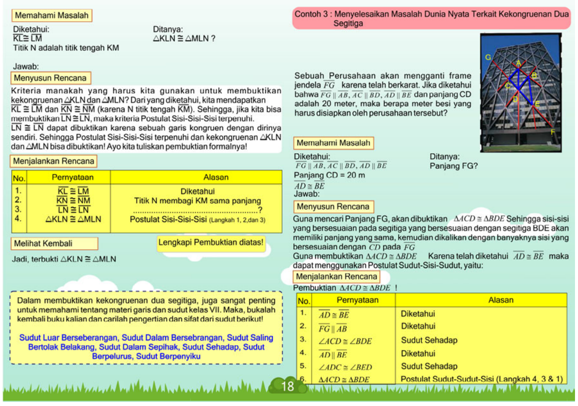

Fig. 5. The content of Polya's problem-solving steps.

C. Development Phase

The development process begins with installing essential software, including CorelDraw X8 (64-bit) for module design, Google Chrome App: QR Code Generator for QR code creation, Adobe Flash Professional CS6 for 2D animations, Video Cutter Editor for video editing, Unity 2019.1.1f1 (64-bit) for MoAR building, and Vuforia Engine for augmented reality applications within Unity software.

The print learning module was developed by using CorelDraw X8 with A4 (210 × 297 mm) landscape orientation. QR codes are generated with the Google Chrome QR Code Generator extension app, were initially in *.png and converted to *.jpg in CorelDraw X8 with added border lines for proper placement.

MoAR was developed by using Unity 2019.1.1f1 (64-bit), while CorelDraw X8 was used for background design. QR codes, serving as markers, were uploaded to developer.vuforia.com and then imported as a Unity package. 2D animation videos were produced by using Adobe Flash Professional CS6, exported as *.avi, converted to *.mp4 via Format Factory, and edited by using Video Cutter Editor. Unity 2019.1.1f1 (64-bit) combined all videos, animations, and markers into the final application.

D. *Implementation Phase*

The implementation of the MoAR-integrated printed learning module was conducted through the implementation of a flipped classroom. The idea behind the flipped classroom is to utilize the out-class phase for students to learn, while the in-class phase is dedicated to evaluation and task completion [43]. The experimental and control classes underwent eight meetings, the experimental class was accompanied by the MoAR-integrated printed learning module. Additionally, a control group was included, which followed the conventional flipped classroom with out-class and in-class phases.

All learning steps are conducted based on the embedded 9E Learning Cycle within the MoAR-integrated printed learning module.

1) *E-1: Elicitation*

This step is aimed at triggering interest in learning the upcoming chapter. In addition to the availability of videos, this phase also presents an engaging narrative about how the upcoming learning material functions in the real world. This is intended to boost the enthusiasm and learning motivation of students at the beginning of the learning process (Fig. 6).

Students will be introduced to the application and real-life significance of the chapter being discussed through a video that will appear when scanned using MoAR. (Fig. 7).

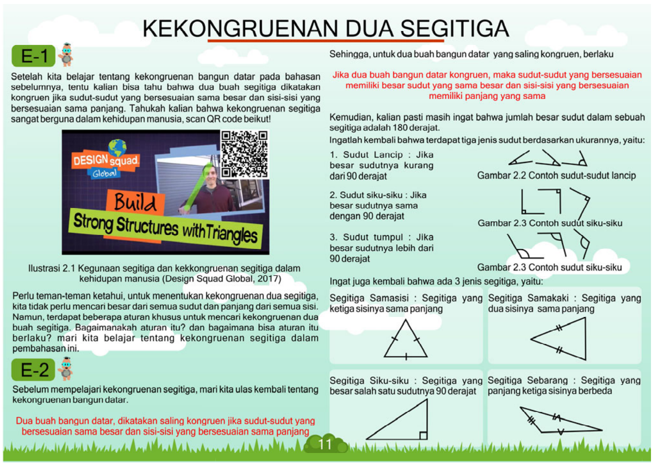

Fig. 6. E-1 and E-2 in the MoAR-integrated printed learning module.

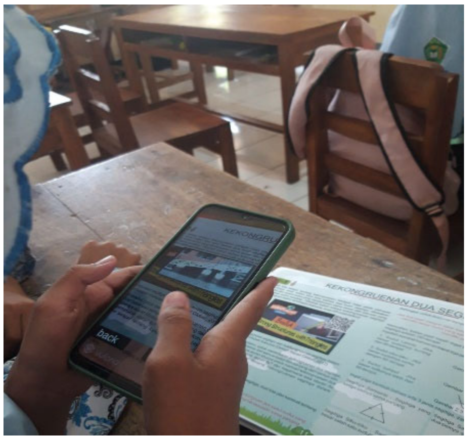
Fig. 7. Implementation of elicitation phase by student.

2) *E-2: Engagement*

This phase is carried out by exploring students' prior knowledge of the relevant learning material to be used in the upcoming learning. The learning module provides a discussion of prerequisite material to master the upcoming learning material (Fig. 6).

3) *E-3: Exploration and E-4: Explanation*

E-3 and E-4 are presented simultaneously in the learning module. This is because the learning activities and material explanations in self-directed learning cannot be separated as shown in Fig. 8.

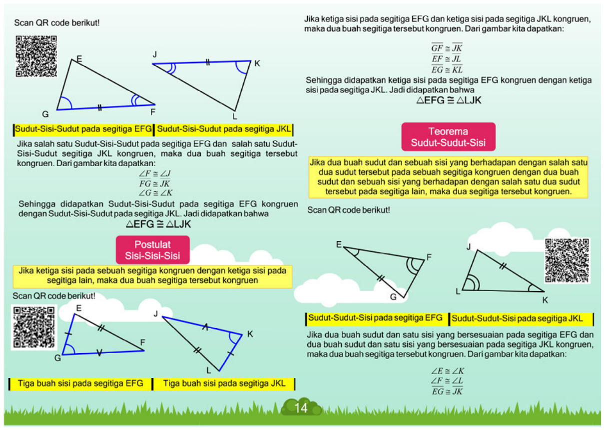

Fig. 8. E-3 and E-4 in the MoAR-integrated printed learning module.

The MoAR-integrated printed learning module provides a QR code that is scanned using MoAR to enhance the visualization of the geometry objects being studied, as shown in Fig. 9.

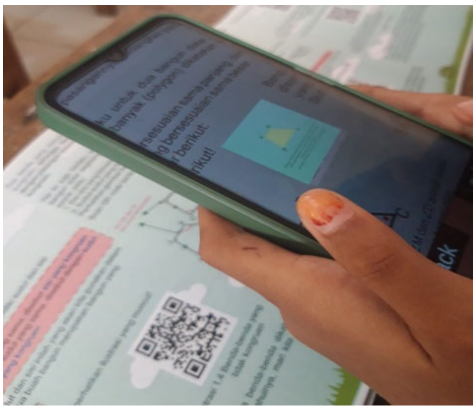
Fig. 9. The application of AR in E-3 and E-4 within the learning module.

4) E-5: Echo

The Echo phase is characterized by providing a summary of the material and examples of problems containing concepts and issues related to the material in daily life. The mathematical problem-solving steps presented are based on Polya's problem-solving steps, as shown in Fig. 10.

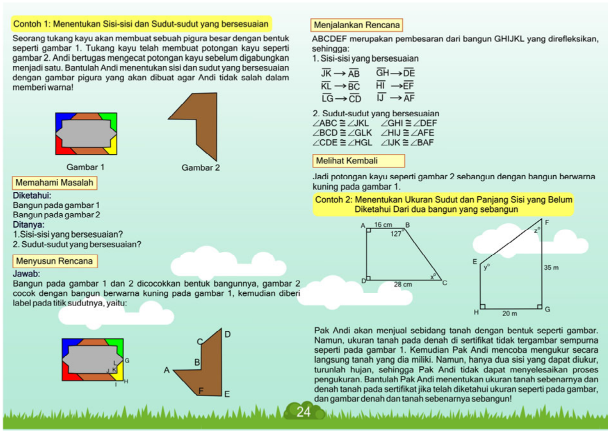

Fig. 10. E-5 in the MoAR-integrated printed learning module.

5) E-6: Elaboration

To test the intellectual aspect of students' abilities, challenging problems are provided regarding contextual understanding and problem-solving ability, as seen in Fig. 11. This phase aims to assess students' higher-order thinking skills through complex problem-solving scenarios and contextual comprehension.

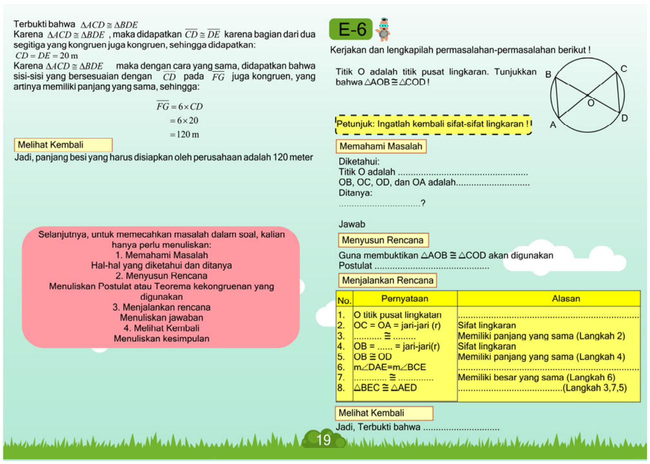

Fig. 11. E-6 in the MoAR-integrated printed learning module.

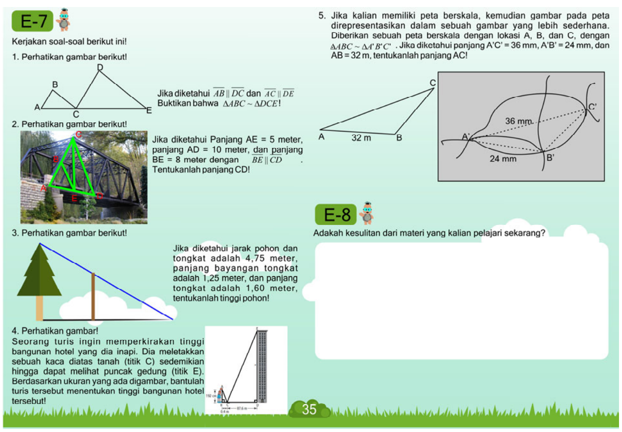

Fig. 12. E-7 and E-8 in the MoAR-integrated printed learning module.

6) E-7: Evaluation

Five questions are presented to assess the level of student's conceptual understanding and problem-solving abilities related to the learned material, as depicted in Fig. 12.

7) E-8: Emendation

In this phase, blank boxes are provided at the end of each sub-topic that can be filled by students if they encounter difficulties and find the material unclear during the learning process using the learning module, as seen in Fig. 12.

8) E-9: E-Search

The final phase of the 9E Learning Cycle involves the use of technology in learning. This phase is implemented through the use of an Android smartphone to scan QR codes that will display animated videos and several videos retrieved from a video browser site. The integration of technology aims to enhance the learning experience by providing dynamic visual content and interactive materials, fostering a more engaging and effective learning environment for students.

E. Evaluation Phase

The evaluation phase has three parts: validity, practicality, and effectiveness evaluation.

Validity evaluation and revision: The expert validation process was carried out online by using Google Forms and the ZOOM video conferencing application, involving seven experts. The validation sheet encompassed three aspects with indicators as presented in Table 9. The results of the validation can be seen in Table 10.

Table 9. Indicator of experts' validation aspects

Aspect	Indicators
Content Quality	Truthfulness, accuracy, balanced presentation of ideas, and appropriateness in the level of detail (breadth and depth).
	Complete coverage of all learning materials from one unit of competence or sub-competence within a single module.
	Alignment between learning objectives, activities, and assessment with the characteristics of the learners.
Design Presentation	Design of visual and audio information to enhance learning and efficient mental processing.
	Ease of navigation, interface predictability, and quality of interface help features.
Quality in Supporting Learning	The ability of the module to enable learners to self-teach using the developed module.
	Independence of the developed module from other separate learning sources for studying the material or completing tasks.
	Usability in various learning contexts and with learners from diverse backgrounds.

Table 10. Results of experts' validation

Aspect	Question	Coefficient-V Score	Validity Level
Content Quality	R1	0.96	Valid
	R2	0.86	Valid
	R3	0.89	Valid
Design Presentation	R4	1.00	Valid
	R5	0.89	Valid
Quality in Supporting Learning	R6	0.93	Valid
	R7	0.86	Valid
	R8	0.96	Valid
Average		0.92	Valid

The expert validation analysis revealed that all three aspects received valid ratings, as indicated in Table 10. The Coefficient-V scores in Table 10 were aligned with the validity categories outlined in Table 5, providing insights into the validity level for each V-coefficient score obtained. These findings affirm the validity of the MoAR-integrated printed learning module. However, despite receiving a valid rating, minor revisions are still needed based on the comments from the experts. The following are the revisions made based on the experts' comments, detailed in Table 11.

Table 11. Revisions based on experts' comments

No.	Before revision	After revision
1.	The color selection is too bright and lacks contrast between the text, illustrations, and background. This creates discomfort to the eyes when reading for a long time.	The colors are changed to pastel colors that are softer and have higher contrast between the text and background, making it more comfortable for prolonged reading.
2.	Clear instructions should be provided to emphasize the scanning of QR codes.	Each QR code is accompanied by a caption instructing users to scan the QR code provided.
3.	The caption for geometric shapes is not accurate as it uses the term "figure."	The caption for geometric shapes is revised from using the term "figure" to "illustration."
4.	The interior of geometric shapes does not need to be filled with color.	The interior of geometric shapes is made transparent to only show the sides, as coloring them is not in line with their definition.
5.	The MoAR application is divided into four separate applications based on the number of sub-topics in the learning module.	The MoAR application is consolidated into a single application for the convenience of students in downloading and operating the app, eliminating the need to install and uninstall multiple applications.
6.	Buttons on the MoAR scanner page for displaying augmented reality videos and animations should include a back button to return to the main menu.	Buttons on the MoAR scanner page for displaying augmented reality videos and animations are supplemented with a back button to allow users to return to the main menu.

Practicality Evaluation: The practicality score is based on the assessment results from the questionnaire filled out by students after engaging in learning activities using the MoAR-integrated printed learning module. In Table 12, the indicators for each practicality aspect assessed are presented.

The following presents the results of the analysis based on students' responses. The percentage results are matched with the practicality categories outlined in Table 6, thereby determining the level of practicality.

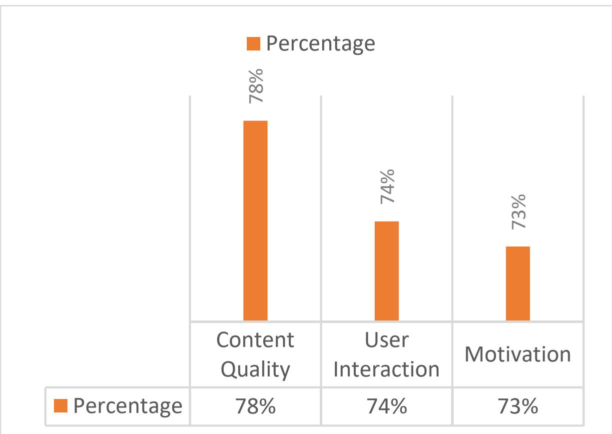

Fig. 13. Analysis of practicality based on students' responses.

Table 12. Students' responses indicators

Aspect	Indicators
Content Quality	The content in the module is organized sequentially and systematically for ease of understanding.
	Complex material is presented simply, clearly, and without confusion.
	The examples and tasks provided are comprehensible and straightforward.
	Questions and problems in the module are well understood.
	The module includes supportive images, illustrations, and animations to facilitate understanding of the material.
	The text is readable, and the module's appearance and color scheme are appealing.
	Augmented reality animations, images, and graphics in the module are of high quality and aid in understanding.
	The module's layout is concise, clear, and aesthetically pleasing.
	The balance of text, images, animations, and illustrations in the module supports easy comprehension of the material.
	The content of text, images, animations, and illustrations matches the discussed information and is well-placed.
User Interaction	The operation of the learning module and its components is trouble-free.
	Links to augmented reality animations, images, and other graphics are easily accessible and well-placed.
	Using the learning module and its components does not cause difficulties.
	The content and supporting media in the learning module are responsive.
	The module offers constructive suggestions for knowledge enhancement.
	The learning module is suitable for use during study sessions.
Motivation	From start to finish, the learning module engages and retains interest and attention.
	Enthusiasm for learning with the module remains high throughout the course.
	There is a consistent eagerness to solve all the problems presented in the learning module.
	The module is comprehensive, eliminating the need for additional teaching materials during learning.
	The materials in the learning module can be understood without seeking external sources.

Based on Fig. 13, it is found that the average practicality score obtained from student responses after learning using the MoAR-integrated printed learning module is 75%. This result indicates that the developed products have met the practicality criteria with a predicate of very practical.

Effectiveness Evaluation. The effectiveness of the MoAR-integrated printed learning module was assessed through the implementation phase involving the experimental and control classes. The pretest and posttest scores of the participants are presented in Table 13.

Table 13. Descriptive statistics for pretest-posttest data analysis

Class	Test	N	Mean	Std. Dev.	Min.	Max.
Control class	Pretest	34	70.24	4.61	60	78
	Posttest	34	83.18	4.09	74	90
Experiment class	Pretest	34	71.24	4.39	61	79
	Posttest	34	88.65	3.75	78	95

After obtaining the pretest and posttest scores, an analysis using N-Gain was conducted, which resulted in N-Gain scores. Subsequently, a comparative test was performed on the N-Gain scores. Before this, a normality test was conducted using the Shapiro-Wilk test, which indicated that the N-Gain scores for both the experimental and control groups were normally distributed, with a p-value of $0.8933 > \alpha = 0.05$ for the experimental group and $0.3914 > \alpha = 0.05$ for the control group. Furthermore, a homogeneity test was conducted using Levene's test, which indicated that both groups came from populations with equal variances, with a p-value of $0.0835 > \alpha = 0.05$. Therefore, the prerequisites for conducting an inferential parametric independent samples t-test were met, which showed that p-value = 3.093e-13 < α = 0.05. Consequently, it was found that the average improvement in mathematical problem-solving abilities for students in the flipped classroom learning with an MoAR-integrated printed learning module was greater than the average improvement for students in the control group using conventional flipped classroom learning.

F. Discussion

1) The validity of MoAR-integrated printed learning module

The MoAR-integrated printed learning module is divided into two inseparable parts. The first is a printed learning module, and the second is an Android application named MoAR. Expert evaluations of the MoAR-integrated printed learning module show valid criteria in aspects of content quality, design presentation, and quality in supporting learning (Table 10). The developed learning module adheres to the accuracy of the learning material, complemented by the visualization of mathematical objects through AR.

Content quality is a critical aspect when developing learning media [34, 44, 45]. Furthermore, in addition to being evaluated for the accuracy and clarity of the learning material presented, the learning module in this study is also assessed for its alignment with the definition of a learning module [46, 47], which includes the comprehensive coverage of the learning material and the harmony between the material, activities, and evaluation with the learning objectives. This aligns with the research by Dewi and Maulida [48] which indicates that a learning module encompasses educational content for a specific sub-competency, complete with activities and learning evaluations. The difference in this study is that the material covered involves the system of linear equations in two variables, whereas in the MoAR-integrated printed learning module, it is congruency and similarity of plane figures.

The MoAR-integrated printed learning module also pays attention to design presentation by showcasing interfaces of the printed learning module and MoAR apps which display attractive, bright colors, and are user-friendly (Figs. 2 and 3). This design presentation is also an essential aspect of prior research in developing an AR application [49, 50]. Furthermore, the digital display through AR is designed clearly and follows correct mathematical principles. In addition, to foster problem-solving abilities, the learning module developed in this study incorporates Polya's problem-solving steps [42] as a training basis to improve students' mathematical problem-solving abilities when faced with mathematical problems [51, 52]. Previous studies have also developed learning modules focused on improving problem-solving abilities [53–56]. It is recognized that the focus of these modules is to enhance problem-solving capabilities through their learning steps. In this study, besides using the syntax of the learning model, it also includes problem-solving steps when facing mathematical problems, as shown in steps E-5: Echo and E-6: Elaboration in the 9E Learning cycle.

2) The practicality of MoAR-integrated printed learning module

Based on the practicality test results obtained from the trial at the junior high school, it was found that the MoAR-integrated printed learning module has a practical predicate with a practicality score of 78% for content quality, 74% for user interaction aspect, 73% for motivation aspect, and 75% for the average practicality score, earning the predicate 'very practical.' The first aspect evaluated is content quality focusing on the ease of understanding the material and its delivery method. The MoAR-integrated printed learning module has a syntax basis of the 9E learning cycle (Table 8) as the basis of the learning model to make the entire material presentation systematic and organized. This aligns with the research by Hidayat *et al.* [57] who used the Problem-Based Learning (PBL) model in an ePub-based electronic learning module.

The use of the learning model syntax in the learning module also supports self-directed learning among students. The 9E learning cycle syntax makes it easy for independent use. This is in line with the research by Amaliyah *et al.* [58] which revealed that the use of learning modules in self-directed learning can influence students' self-regulated learning. The interaction between users and the developed learning module is also an important aspect of this study. Following the needs analysis, the learning module is designed in a printed form enriched with AR visualization. Research by Cahapay *et al.* [59] indicates that the printed form in modular learning has many advantages regarding the flexibility of use, but has limitations in its need to use other learning resources to present abstract and practical content. However, in this study, these limitations are overcome with AR.

Additionally, the use of the MoAR-integrated printed learning module also enhances student motivation. The incorporation of AR in a printed learning module is capable of boosting students' motivation to complete each learning step. This aligns with the definition of learning modules and previous research related to the use of AR technology in increasing student motivation [47, 49, 60].

3) Effectiveness of MoAR-integrated printed learning module

The use of AR technology represents an innovation that addresses the limitations of printed modules in providing object representations [50]. Furthermore, the use of AR technology in learning has been proven to enhance various skills and abilities in cognitive, psychomotor, and affective domains [61–63]. The MoAR-integrated printed learning module serves as an effective learning resource for teachers to improve students' mathematical problem-solving abilities.

The MoAR-integrated printed learning module is developed to improve students' mathematical problem-solving abilities. There were 68 students participating in demonstrating their level of mathematical problem-solving abilities in a flipped classroom setting. The results indicate that the class using the MoAR-integrated printed learning module experienced a higher average improvement in mathematical problem-solving abilities compared to the class using conventional flipped classroom learning. These findings align with Nadzri *et al.* study that the use of AR modules can enhance students' achievement in mathematics [32]. In addition to presenting a new approach to learning, the use of AR in the learning toolkit impacts the effectiveness of learning and can even enhance spatial ability in mathematics lessons, influencing students' ability to solve mathematical problems [26, 64].

IV. Conclusion

This research concludes that the MoAR-integrated printed learning module has been deemed suitable for use in the teaching and learning process. The conclusion is based on the validation results by seven experts, which indicated its validity in terms of content quality, design presentation, and quality in supporting learning. Furthermore, from the responses of the student users, it was found that the developed product has several advantages in terms of content presentation, user interaction, and motivation. The content is presented in a systematic and organized manner, with smooth operability, and the ability to engage students in learning. Additionally, this is further substantiated by its effectiveness in improving mathematical problem-solving abilities through inferential statistical testing. Furthermore, the novelty of this research lies in the creation of the MoAR-integrated printed learning module, which comprehensively covers both material delivery and evaluation. The developed learning module does not merely highlight the aspect of AR technology but also offers flexibility in use due to its printed form, organized according to the 9E learning cycle syntax and problem-solving steps. Additionally, AR technology is embedded to overcome limitations in visualizing mathematical objects. In accordance with its definition, the learning module in this study can be conducted independently as it is systematically structured based on a learning model syntax. Suggestions for future research encompass crafting more targeted AR content tailored to specific mathematical subjects and examining the enduring effects of AR utilization on enhancing mathematical proficiency.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Arif Rahman Hakim was primarily involved in writing, conceptualization, designing, and analysis. Kartono provided critical review and supervision throughout the project. Wardono contributed to the analysis, designing, and supervision aspects. Adi Nur Cahyono was responsible for editing and reviewing the manuscript. All authors have reviewed and approved the final version of the manuscript.

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