



AR-Assisted RME Model in Enhancing Mathematics Learning Outcomes and Literacy of Teacher Professional Education Students

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Abstract: The purpose of this study is to develop AR media based on Realistic Mathematics Education (RME) that is valid, practical, and effective in improving learning outcomes and literacy of Teacher Professional Education (TPE) students in basic mathematics lessons. The novelty of the study lies in the combination of AR media and the appropriate RME model at the TPE student level. The research method used the ADDIE development model. The number of respondents was 50 TPE students from Pasundan University, which divided into two classes. The mean scores for validity, as assessed by material experts, were 92.11%; learning model experts, 92.22%; media experts, 92.39%; and lecturers, 92.39%, with all categories demonstrating very high validity. For the mean practicality of student assessment of AR media and RME models, the mean was 92.01%, which falls into a very good category. A significant increase was observed in small group trials using AR Media based on the RME model, which has been proven effective, as evidenced by a 29.6-point increase from pre-test scores of 61.2 to post-test scores of 90.8. In large group trials, differences in learning outcomes were found between students who used AR media based on the RME model, with a mean of 90.8, and students who used other media based on the discussion model, with a mean of 69.5. The difference proved effective and very significant, with a mean difference of 21.3. Conclusion: Using RME-based AR media in mathematics learning for TPE students is more effective than using media with other learning models. The implication of this study is that TPE lecturers should encourage the implementation of AR media based on the RME model in the learning process.

Keywords: design, mathematical literacy, AR media, RME.

▪ INTRODUCTION

In the development of 21st-century technology, a new problem has emerged, namely the low basic mathematical literacy skills of students, especially Teacher Professional Education (TPE) students (Hidayat & Firmanti, 2024). This problem has been a long-standing issue in Indonesia and has been the subject of numerous national and international studies. The 2011 TIMSS survey showed that Indonesian students' mathematics achievement was below the average for other countries, with a global mean score of 500, while Indonesia's average score was 400-420 (Hermanu, Sari, Sondari, & Dimiyati, 2024). At the university level, a study of students found that only about 15% of students were in the high literacy category, 63% were in the medium category, and 22% were still in the low category in basic mathematics (Pascual, Caballero Mariscal, Pinto, & Marín-Jiménez, 2025). This indicates that students' basic mathematical literacy, including the ability to interpret, formulate, and apply concepts, remains weak. This is a common problem underlying the low basic mathematics skills of TPE students, who will become future educators. A specific issue for TPE students is the study program report, which shows that in the substantive TPE test, consisting of 15 questions and a 30-minute time limit, 70% of participants failed to achieve the minimum competency score. In contrast, only about 30% passed the basic standard score (Aragón, Menacho, Navarro, &

Aguilar, 2024). During training to strengthen probability and data material for TPE Mathematics students, the average score increased from 55 before the training to 72; however, it was still far from expectations (Sad & April, 2024). In the statistics course, the literacy skills and learning outcomes of TPE students remain minimal, with an incomplete relational understanding. All of this indicates a weakness in achieving learning outcomes and a lack of basic mathematical literacy among TPE students, specifically difficulties in interpreting images, graphs, and concepts, as well as formulating mathematical models from context, and applying logical reasoning to contextual problems. The current problem of basic mathematics learning design is also reinforced by data, where the results of the TPE student learning design evaluation show that the ability to compile mathematics lesson plans is still in the low category, around 30% of the 90% still lack understanding of the media, learning models used, and compiling teaching materials (Trapero-González, Hinojo-Lucena, Romero-Rodríguez, & Martínez-Menéndez, 2024). The resulting learning design remains highly normative and procedural, with minimal implementation of learning models. While it is assumed that a reality-based model like RME can be used by TPE students, theory suggests that effective learning must include the exploration of real-world phenomena, mathematical modeling, social interaction, and vertical and horizontal mathematization that is appropriate to the participants' abilities (Shvarts, Bos, Doorman, & Drijvers, 2024).

The problems in previous research regarding TPE students' basic mathematical understanding were also concrete. Although there was an improvement after the discussion model intervention, the mean numeracy literacy score was only in the range of 70–75. It had not yet reached the high category of higher than 85, which corresponds to the TPE graduates standard (Nickow, Oreopoulos, & Quan, 2024). A meta-analysis study specifically for RME in Indonesia concluded that 95 were categorized as having a strong influence on students' mathematical literacy with the help of media (Anugraheni, Gufron, & Purnomo, 2025). However, most studies using Augmented Reality (AR) media and RME models have been conducted on elementary and junior high school students, which aligns with the goal of TPE students becoming teachers. Another meta-analysis in Turkey showed moderate to high effects of AR media and RME compared to traditional methods (Russo, Kalogeropoulos, Bragg, & Heyeres, 2024). This indicates that AR and RME media, both used separately and in combination, have been proven effective in schools, but their application to prospective teachers is still limited and lacks quantitative evaluation.

The integration of the Realistic Mathematics Education (RME) model with Augmented Reality (AR) offers significant potential in addressing various challenges faced by students in teacher preparation programs (TPE). Theoretically, RME provides a structured and systematic framework for developing student competencies, while AR offers an interactive learning experience (Nkopodi, Jakovljevic, & Photo, 2024). By combining the RME model with AR, student engagement can increase by up to 45% and their understanding of mathematical concepts can improve by 38% (Mei & Marini, 2025). This is thanks to AR's ability to provide realistic three-dimensional visualizations, making it easier for students to understand abstract subjects such as mathematics. This integration can overcome the problem of low motivation and self-confidence often faced by TPE students due to traditional learning methods (Reilly, Sheridan, & van der Jagt, 2025). By integrating RME and AR, students can learn independently, conduct practical

simulations, and receive direct feedback, thereby effectively improving their pedagogical competencies (Sadati et al., 2024). The approach with the RME model and AR media produces innovations that can overcome the limitations of traditional education by increasing the effectiveness and enthusiasm of the teaching and learning process for TPE students (Nhleko, Aroba, & Chisita, 2024).

The theory underlying the development of this learning design is Freudenthal's Realistic Mathematics Education (RME) approach with AR media, which emphasizes five main principles: phenomenological exploration, progressive mathematization and modeling, student construction, interactivity, and the interconnectedness of media and learning models (Researches, 2025). RME supports mathematics as a human activity, starting from real contexts and building vertically from the concrete to the abstract, while media helps in presenting real-world representations (Risdiyanti, Zulkardi, Putri, Prahmana, & Nusantara, 2024). Modern mathematical literacy theory defines literacy as the ability to formulate, use, and interpret mathematical concepts in real-world contexts in line with the goals of RME (Fajri, Marini, & Suyono, 2025a). In TPE, students with a combination of RME theory, media, and AR strengthen mathematical literacy and strengthen pedagogical foundations and instill skills in obtaining learning outcomes (Mediana, Funa, & Dio, 2025).

The urgency of this research is due to the minimal learning outcomes and understanding of TPE students in mathematics courses. 85% are in the moderate and low categories. Design, model, and media interventions in learning are essential. Another urgency is that the future curriculum requires prospective teachers who are able to build student literacy and numeracy through media-assisted learning models. The gap lies in the RME model and AR media that have been implemented in elementary and secondary schools and have never been applied to TPE students due to differences in context, needs, and learning design objectives. For students, the main focus is mastery of basic mathematical content and improving numeracy literacy. Meanwhile, TPE is not only required to master the material but also has a dual responsibility as prospective educators. TPE must understand concepts in depth while being able to design effective pedagogical strategies. TPEs' cognitive level is higher; their learning experiences are more complex, and their learning motivation is more closely tied to professionalism and career preparation. The findings regarding the effectiveness of the RME model and AR media on elementary school students are indeed strong. However, their application to TPE requires adaptation, as the orientation is not only on the application of concepts but also on reflective skills, learning design, and the integration of theory into teaching practice.

The research question is whether a mathematics learning design based on RME, with the help of Augmented Reality (AR) media, is suitable for improving the basic mathematical literacy of TPE. This study also examines the validity, practicality, and effectiveness of the learning design applied to TPE, considering the diverse backgrounds and learning needs of school students. How are the differences in learning outcomes and understanding of basic mathematical literacy between TPE who follow RME-based learning with the help of AR compared to those who use other, more conventional learning models? The purpose of this study is to develop a mathematics learning design based on RME, utilizing AR media, that is valid, practical, and effective in meeting the needs of TPE students. Another objective is to test how much influence the design has in improving learning outcomes and understanding of basic mathematical literacy of TPE

and the final objective for evaluating learning outcomes between TPE using the RME model design and AR media with TPE using traditional learning models, so that a clear difference can be obtained regarding the effectiveness of this innovative approach in the context of teacher professional education.

▪ **METHOD**

Participants

The participants in this study were all students of the Teacher Professional Education Program (TPE) in the education study program at Pasundan University. The sample size consisted of 50 students, divided into two groups: an experimental group of 25 and a control group of 25. All participants were prospective mathematics teachers undergoing professional education and holding a bachelor's degree in pure mathematics and education. The sampling technique was cluster sampling. The subjects during the small group trial were 10 people randomly selected from two classes of 50 students. Meanwhile, for the large group trial, they were divided into two groups: 25 people who tested the RME model and AR media, and 25 people were given conventional media and a discussion model. This division aimed to evaluate the practicality and effectiveness of the RME model and AR media approach in enhancing the learning outcomes of TPE students in basic mathematics courses, specifically in areas such as problem interpretation, reasoning, symbolic representation, and mathematical communication.

Research Design and Procedures

The research approach uses the ADDIE development model, which consists of five phases, namely analysis, design, development, implementation, and evaluation (Kabuye Batiibwe, 2024). The ADDIE Model was chosen because it was deemed appropriate for developing a structured, user-focused learning design using AR media and the RME model. This model was implemented sequentially to ensure integration of the development process, from identifying needs to evaluating effectiveness through testing. The following steps outline the ADDIE Model used in this study. The following steps outline the ADDIE Model used in this research are presented in Figure 1.

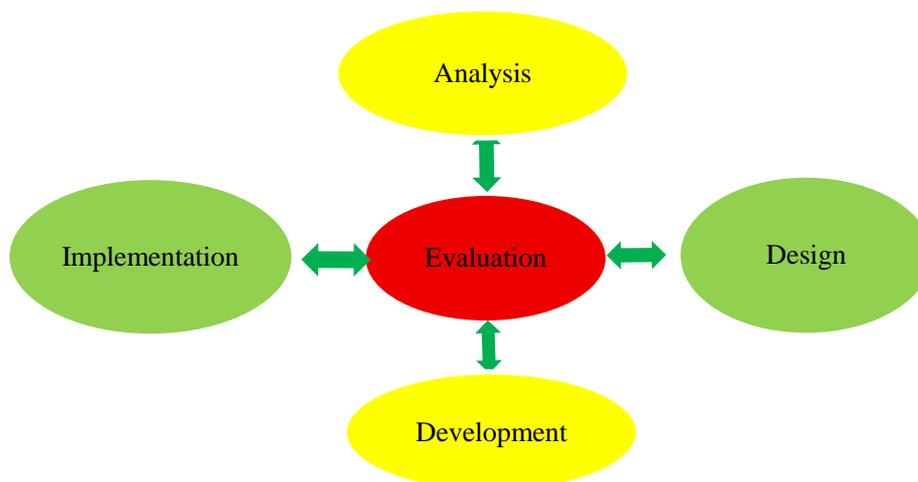


Figure 1. Flowchart of ADDIE mode

The ADDIE Steps Used in this Study Were as Follows

The analysis stage included identifying the learning needs of TPE students, including learning outcomes, mathematics learning difficulties, obstacles in designing mathematics lessons, a literature review, and the need for a learning model. The learning model design was reviewed through observation, documentation, instruments, and interviews with TPE students. The collected data were evaluated and became the basis for designing appropriate, practical, and effective RME media and learning models to improve TPE learning outcomes and enhance the mathematical literacy of prospective professional teachers.

Planning Stage (Design): The developed design includes materials, sub-materials, learning objectives, basic mathematical literacy indicators, context-based learning activities, evaluation strategies, and learning media, utilizing the RME model and AR media. The design focuses on TPE evaluation to build mathematical concepts through contextual problems relevant to everyday life, such as graphs and relationships between materials. The material is arranged in stages, starting from exploratory activities to formal mathematical awareness. In addition, lesson plan sheets and assessment instruments are designed to cover problem interpretation, symbolic communication, literacy skills, and mathematical reasoning. All components are designed in an integrated manner to support the achievement of learning objectives. This initial design serves as a basic draft to be validated by subject matter experts, learning model experts, learning media experts, and colleagues.

This development stage involves implementing the RME model and AR media in the designed mathematics learning. The products developed include mathematics materials, RME learning model designs, and Augmented Reality (AR) media. All are structured based on the RME model approach and depict real-world materials as an attraction of interest and a way to understand literacy and concepts. All products prepared in draft form are submitted for validation to material experts, learning model experts, media experts, and lecturers as colleagues. All validators provide recommendations for improving the materials, models, and media used. Validators provide scores for products that this study has improved. Evaluation is carried out based on validation scores, and the evaluation results serve as the basis for researchers to continue refining the product to meet the feasibility standards before conducting a limited trial with 10 TPE students and a large-group trial with 25 students.

The implementation phase involves implementing the designed and validated learning plan. This implementation is carried out in two stages, namely to small-group and large-group trials of TPE students. The RME model and AR media were trialed with the lecturer acting as a facilitator and TPE students as active participants. Before the small group trial, a pre-test was conducted to measure the initial abilities of TPE students, after which the material was applied with the RME model and AR media. After the learning process was completed, instruments were administered to measure the practicality of the AR media and the RME model, as well as learning outcomes. A post-test was also given to a small group of students to serve as the basis for refining the media and models before the large group trial. During this implementation phase, a large-scale trial was also conducted with 50 TPE students, of whom 25 used AR media and the RME model in their learning. In contrast, the other 25 used alternative models without the media. Before the implementation of the RME model and AR media, the researcher administered the pre-test. During the implementation phase, TPE students were involved in solving real-world

problems relevant to their lives, such as calculating and creating diagrams from the material given. The learning process emphasized exploration, group discussions, and individual reflection. During this process, researchers observed the activities of TPE students and the implementation of their learning plans according to the prepared learning plans. TPE students were also asked to fill out an instrument to provide feedback on their learning plans, and at the final stage, a post-test was administered. The evaluation results from this data were used to determine the extent to which the RME model and AR Media were effective in improving learning outcomes, enhancing understanding of mathematical literacy, and increasing acceptance among TPE students.

The evaluation stage of this study was conducted to assess the effectiveness of the RME model and AR media in enhancing the basic mathematics learning outcomes and mathematical literacy skills of TPE students at Pasunda University. The evaluation was carried out continuously, starting from analysis, design, development, implementation, and seeing the practicality and effectiveness through instrument assessment, pre-test, and post-test results, tests, and comparison of learning outcomes of TPE students who used AR media and the RME model with students who did not use the media and the RME model.

Instrument

The instrument was systematically developed to ensure measurement validity and reliability. The first step was to identify constructs that measure the quality of RME-based learning design utilizing AR media. From these constructs, several indicators were derived, including aspects of RME content, material presentation, suitability for mathematical literacy, contextual assessment, language clarity, and ease of media understanding. Next, these indicators were formulated into statement items using a five-point Likert scale, from "strongly disagree" to "strongly agree." The developed instrument then underwent an expert validation stage, involving mathematics education lecturers and media experts to assess the relevance, clarity, and consistency of the items. Input from the experts was used to refine the wording and eliminate indicator redundancy. After revision, the instrument was piloted on a small group of TPE students to test comprehension and consistency of answers. The pilot results were analysed quantitatively to ensure reliability before the instrument was finally used on a larger group as an official measurement tool. The test was also designed to measure pre- and post-test scores, and this test was validated by subject matter experts. The test instrument was also developed and adapted for the RME model and AR media indicators. This test was used to observe the improvement in learning outcomes before and after the application of AR media and the RME model in basic mathematics learning by TPE students, as well as to measure the differences between students who used AR media and the RME model and students who used other media and conventional learning models. Data collected through the instruments and tests were analysed quantitatively to produce percentage scores for each indicator. The results of this instrument serve as the basis for evaluating the quality of the developed learning process and provide important input for revising and refining the RME model and AR media.

Data Analysis Techniques

The analysis technique used is descriptive statistics by analysing the feasibility, practicality, and effectiveness of AR media and RME models. Analysis of validation

scores from material experts, learning model experts, media experts and colleagues in measuring feasibility, instrument assessment scores by TPE students to measure the practicality of AR media and RME models as well as pre-test, post-test in small group trials and in large group trials and see the comparison of the mean learning outcomes of TPE students who use RME models and AR media with TPE students who do not use AR media and do not use RME models. The results of expert validation are the basis for continuing to improve AR media and RME models until the product is in the very feasible category. Interpretation is very feasible if the validity of the interpretation results is very valid. To determine validity, starting from the score range of 0–19% is very invalid, 20–39% is less valid, 40–59% is quite valid, 60–79% is valid, and 80–100% is very valid. The results of TPE students' assessments using instruments on the product during implementation serve as the basis for determining its practicality. Meanwhile, the average pre-test and post-test results serve as the basis for determining effectiveness. The minimum criterion for Practicality is an average of 80%, while for Effectiveness, an average post-test score above 80%. In interpreting the practicality and effectiveness aspects, the categories used are very good in the range of 80-100%, good 60-79%, sufficient 40-59%, poor 20-39%, and very poor 0-19% (Bognar, Mužar Horvat, & Jukić Matić, 2025). This study also compares the learning outcomes of students who were taught using the RME model design and AR media with students who did not use the RME model and AR media. The RME model and AR media are also said to be effective if the post-test results of TPE students using the experimental group mean are above the average of 80 (Vuong & Steklács, 2025). Hypothesis testing in this study was conducted to determine the effectiveness of the intervention. First, an independent-samples t-test was used to compare pre-test scores between the experimental group, which used the RME model design and AR media, and the control group, which used other learning models. Next, a paired-samples t-test was used to analyze the differences in pre-test and post-test scores in each group to determine whether there was improvement. The N-Gain results are interpreted as high if the g-value is higher than 0.7, medium if ($0.3 \leq g \leq 0.7$), and low if the g-value is less than 0.3.

▪ **RESULT AND DISSCUSSION**

Intervention of the RME Model and AR Media in Influencing Cognitive Processes

The results of this study indicate that the integration of Realistic Mathematics Education (RME) with Augmented Reality (AR) can improve the learning outcomes and understanding of TPE students. Students can connect abstract concepts with real-life situations, stimulate the process of consolidating new knowledge with concrete experiences, and connect old memories with new memories. In this study, the results of the RME model design and AR media can form a stable mathematical model for TPE students, thereby reducing cognitive load when encountering challenging materials. AR interactivity fosters active learning through exploration, object manipulation, and contextual simulations, stimulating critical thinking skills and making mathematics learning more engaging, interesting, and effective in developing mathematical knowledge and problem-solving skills.

Results of the Development of the RME Model and AR Media

The research found that it produced an effective basic mathematics learning design for TPE students using the RME model and AR media that can improve learning

outcomes, overcome student difficulties, and enhance students' literacy understanding in basic mathematics courses. This basic mathematics material design, based on the RME model and media, has been validated by material experts, learning model experts, media experts, and colleagues. The research findings show that the development of this learning project is successful and comprehensive in achieving research objectives and is in accordance with the theory of mathematics learning design with the RME model, with the help of media (Anugraheni et al., 2025). The following are the results of developing the ADDIE model to produce a basic mathematics learning design for TPE students using the RME model and media assistance.

The analysis phase involved identifying the learning needs of TPE students, including initial skills, learning difficulties, and barriers. The analysis showed that most TPE students still struggled to understand basic mathematical concepts, especially in real-life contexts. The learning approach used so far was procedural and text-based, thus failing to foster students' reflective and contextual thinking skills. The data showed that only about 15% of students fell into the high mathematical ability category, while 63% fell into the medium category, and 22% fell into the low category. Furthermore, 70% of participants did not achieve the minimum score on the basic mathematical ability test, indicating low abilities in data interpretation, mathematical modeling, and logical reasoning. Analysis of classroom observations revealed that the mathematics learning implemented still minimally applied the RME model, such as exploration of real-world phenomena, progressive modeling, and minimal discussions using the RME model. TPE students tended to focus on memorization procedures without being able to connect these concepts to everyday phenomena. Previous learning methods were text-based and did not emphasize contextual understanding, resulting in TPE students experiencing difficulties in interpreting visual information, modeling mathematical problems, and logical reasoning. To overcome the results of this analysis, learning must be designed based on the basic principles of RME with the help of AR media that is appropriate to the real world. Learning materials designed using the RME and AR models are structured from exploratory activities to conceptual understanding, with presentations based on real-world problems.



Figure 1. Design of opening basic mathematics material using RME

Figure 1. Showing AR media and RME models in basic mathematics lessons designed to introduce concepts contextually, Figure 1 shows that the initial material does not directly present formal definitions but instead presents real-world phenomena that are close to life.

Figure 2 shows a design introducing two students discussing while waiting for the bus to campus. The sub-topics in this design range from exploring phenomena to mathematical modeling. Students are encouraged to identify problems, analyse contexts,

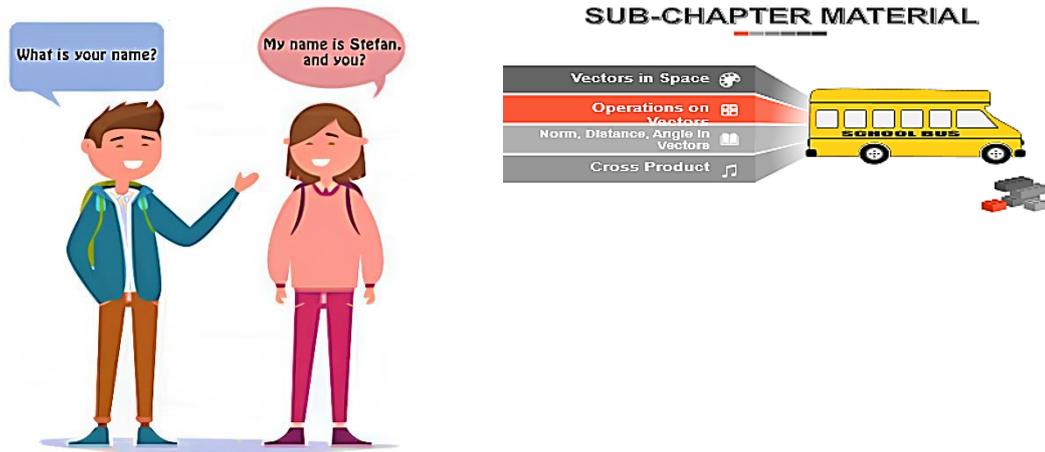


Figure 2. Basic mathematics sub-material with RME design

and develop mathematical models of real-life situations. Structure of Matter presents vector material in a step-by-step manner that supports the Realistic Mathematics Education (RME) approach.

Third axis coordinate determine third field coordinates in dimensions three, namely:

- (a) -YZ Field: Formed field from Y- axis and Z- axis
- (b) -XY plane: Formed plane from X- axis and Y- axis.
- (c) Field -XZ: Formed field from X- axis and Z- axis.

NOTATION ON 3-DIMENSIONAL VECTORS

Notation specifically for 3- dimensional vectors :

i = symbolizes vector unit with direction x
 j = symbolizes vector unit with y
 k = symbolizes vector unit with direction z

then , any vector $u = [a, b, c]$ on vector room stated in form :

$u = [a, b, c] = ai + bj + ck$

Pada gambar disamping, vektor yang mewakili garis berarah \vec{OF} dapat dinyatakan $\vec{OF} = (3, 4, 2)$ Atau $\vec{OF} = 3i + 4j + 2k$

3 Dimensi

Figure 3. Vector learning material design with RME and media

The material structure presents vector material in stages (Figure 3), supported by the RME model and AR media, illustrating the representation of vectors in space that describes their direction and magnitude within a three-dimensional coordinate system. This visualization allows students to understand that vectors are not just abstract symbols, but are closely related to position and motion in real space by adding three-dimensional graphics. This graph facilitates students' understanding of the relationship between vector components (X, Y, and Z axes) in geometric space, aligning with the theory (Yong, Wang, Barton, & Du, 2024) and illustrating the connection between material, models, and media.



Figure 4. Material on vector length norms in lego toys

Figure 4 introduces the concept of the vector length norm, which represents the distance from the origin to the end of a vector in the RME model and AR media, illustrated using Lego toys. This concept is also crucial for mathematical literacy because it involves understanding formulas, relationships between quantities, and implementation in various everyday contexts. Figure 4 serves as a bridge between mathematical abstraction and the real world. This visualization helps TPE students construct the meaning of vectors contextually and mathematically.

The results of the validation of material experts on the learning design using the RME model and AR media. The average validation component of the material experts, with a mean of 92.11% is in the very valid category. This means that the learning design approach for basic mathematics material, using the RME model, is highly feasible and has great potential for improving the learning outcomes and understanding of mathematical literacy among TPE students. The results of the validation by material experts showed that the mathematics learning design based on the Realistic Mathematics Education (RME) model using augmented reality (AR) media had a very high level of feasibility. The material content component had an average of 91.10%, the presentation component 89.90%, the average contextual assessment 93.18%, the suitability of the material with the RE model 90.21%, and the validity of the suitability with basic mathematical abilities 94.12%. The overall average of 92.11%, classified as "very valid," indicates that this learning device meets the feasibility criteria in terms of content, presentation, context, relevance of the learning model, and the expected level of mathematical knowledge. Theoretically, these results are in line with the views of Grafemeijer and Dorman, who stated that the RME model emphasizes contextual and meaningful learning, which allows TPE students to connect mathematical concepts with real-world situations (Fajri, Marini, & Suyono, 2025b). The integration of reality media strengthens Meyer's multimodal learning theory, which emphasizes the importance of interactive visual representations to enhance the understanding of abstract concepts (Marougkas, Troussas, Krouska, & Sgouropoulou, 2023). More realistic materials also facilitate active student engagement, in line with Piaget and Vygotsky's constructivist theories, which place students at the center of the learning process through interaction and exploration (Tasarib, Rosli, & Rambely, 2025). With a high level of applicability, this design has the potential to effectively improve TPE students' mathematical literacy skills, including cognitive, contextual, and problem-solving skills. Meanwhile, the expert validation results of the learning model provided an average score of 94.23% for content, 90.42% for presentation, and 94.51% for assessment. The average score for the model used was 90.90%, and the model's suitability to basic mathematics material was 95.08%. Overall, the average score was 92.22%, which is categorized as highly valid. These results indicate that this learning model meets the eligibility criteria for both small-scale and large-scale trials.

The validation process, conducted by media experts and peers, yielded excellent results with an average score of 92.39%. However, several important inputs were still provided. The experts suggested improving the clarity of the mathematical language to make it more accessible to students from diverse backgrounds, as well as refining the AR visual display to be more consistent and less cognitively demanding. Furthermore, the relationship between the real-world context and the mathematical model was revised to be more explicit, thus optimally supporting RME principles. These revisions were

technical improvements and did not change the core content of the learning design, but rather strengthened the integration between the AR media and the RME model. Specifically, AR-related content scored 91.80%, presentation of material according to RME (91.28%), suitability of AR to AR (92.90%), suitability of AR material to mathematical literacy (92.22%), contextual assessment (91.82%), ease of understanding of material through RME and AR Model (94.31%) (the highest percentage), use of easy-to-understand mathematical language (91.28%), ease of understanding of contextual media (92.90%), and assessment of AR content (92.22%). The use of AR strengthens the cognitive theory of multimodal learning, which emphasizes the role of interactive visualization in facilitating information processing (Zuo, Wenling, & Xuemei, 2025). Previous research by Ibáñez and Delgado-Clos has also shown that AR can improve motivation and learning outcomes through intensive learning experiences. There is also valid data from other components, which contain different designs based on the RME model and the AR media that work on the Internet.

Pilot Study

The results of the Small Group Trial showed a significant increase in the mathematical literacy skills of TPE students after using a Realistic Mathematics Education (RME)-based learning design with the help of Augmented Reality (AR). The average pre-test score was 56.6 and increased to 89.8 in the post-test. This result represents a significant increase of 33.2 points. This improvement reflects the model's effectiveness in helping TPE students understand mathematical concepts more deeply and contextually. AR integration aligns with the Cognitive Theory of Multimedia Learning, which emphasizes that interactive visualizations strengthen conceptual understanding and retention (Md Sabri et al., 2024). Other research has shown that AR can enhance motivation, interaction, and learning outcomes through intensive experiences. Meanwhile, the assessment given by TPE students after completing the small group trial, for the Realistic Mathematics Education (RME)-based learning design indicator assisted by Augmented Reality (AR) for TPE students showed an average score of 92.19% which is classified as "very good and practical in mathematics learning for TPE students in Pasundan". Specifically, the content related to RME obtained a score of 93.13%, the presentation of RME-based mathematics material obtained a score of 92.70%, the suitability of the RME model with AR media obtained a score of 92.15%, the suitability of RME material with mathematical literacy obtained a score of 92.20%, contextual assessment obtained a score of 90.20%, the suitability of the material with the RME model and AR media obtained a score of 93.36% (the highest), the use of easy-to-understand mathematical language obtained a score of 91.80%, the ease of understanding of contextual media obtained a score of 91.90%, and the assessment of repetition of content in RME obtained a score of 92.30%. This finding is in line with previous findings, which show that the use of reality in mathematics learning design with the help of the RME model and AR media can improve students' literacy understanding and learning outcomes (Sunzuma & Umbara, 2025).

The results of TPE student assessments for all product assessment indicators when the group trial was completed, for the Realistic Mathematics Education (RME)-based mathematics learning design assisted by AR, achieved a very good level of practicality, with an average score of 92.01%. Specifically, the content related to RME achieved a

score of 91.70%, the presentation of material according to the RME model (95.40%), the suitability of the RME model with AR (93.60%), the suitability of RME material with mathematical literacy (92.22%), contextual assessment (91.20%), ease of material using RME and AR (91.40%), use of easy-to-understand mathematical language (92.30%), ease of understanding contextual media (93.00%), and reevaluation of RME content (94.90%).

Practicality and Effectiveness Test Results

Small-group trials and large-group trials demonstrated that the mathematics learning design based on the RME model and AR media was highly feasible. TPE students gave assessments with a mean score above 90% for all indicator components. The mean score for ease of understanding of the material using RME and AR was 92.19%, with a score of 93.36%. In the large group trial, the mean score for material presentation using the RME model was 92.01%, with a score of 95.40%. The results of a short interview after implementation, a TPE student said, "Learning with RME-AR makes it easier for me to understand the concepts." Another TPE student said, "AR visualization helps me connect the material concepts with understanding in the real world". A product is considered practical if all assessment components are excellent, and the feasibility of a learning model is influenced by its ability to directly use the design in learning contexts (Mai, Da, & Hanh, 2024).

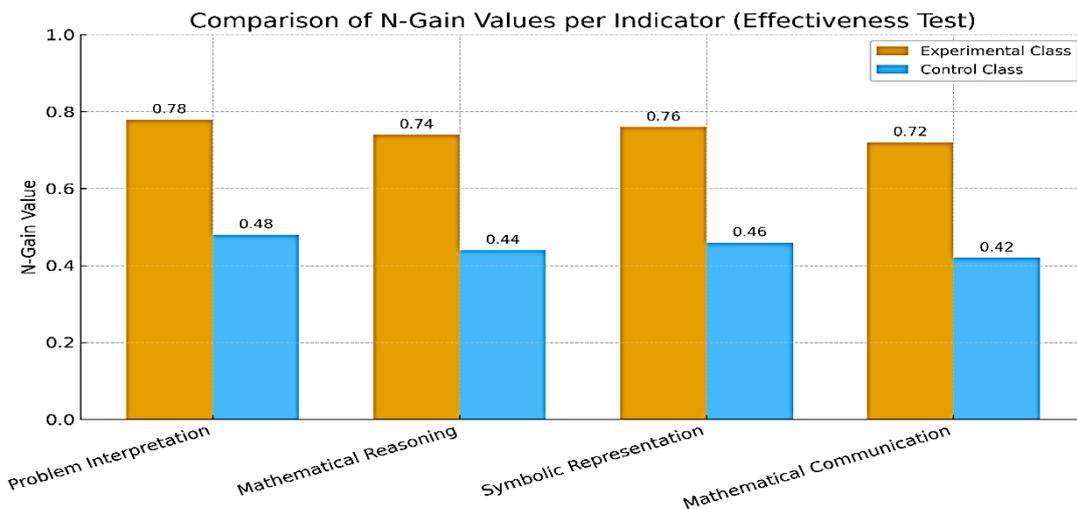


Figure 5. N-Gain of experimental class and control class on test indicator

Figure 5 shows a consistent advantage for the experimental class in all indicators. In problem analysis, the experimental N score was 0.78, compared to the control group's 0.48, resulting in a difference of 0.30. This value indicates a significant increase. For the mathematical reasoning indicator, it reached 0.74 compared to 0.44, indicating an increase in reasoning as a result of the treatment. In symbolic representation, the experimental class's score was 0.76 higher than the control group's score of 0.46. This value also indicates an increase in symbolic representation skills in accordance with the learning objectives. Finally, mathematical communication reached 0.72 for the experimental class and 0.42 for the control group, indicating a significant increase in mathematical communication. In the classification according to the Huck convention, all

experimental scores (0.72–0.78) were in the average to high category, while the control group's mean score was (0.42–0.48). The consistent difference of 0.30 between the four indicators strengthens the argument for the effectiveness of the intervention. In practice, these results indicate that the implemented strategies are more efficient in translating conceptual understanding into thinking, representation, and communication skills. These findings are particularly relevant to future learning design, with an emphasis on incorporating realistic scenarios, providing formative feedback, and engaging in structured collaborative activities.

Table 1. Results of the pre-test–post-test significance test with t-test

Test Type	Comparison	N	Mean pre-test	Mean Post-test	Difference	t-value	Sig. (p)	Interpretation
Pre-test	Experiment (RME + AR).	25	61.2	90.8	29.6	12.47	0.000	There was a significant increase in learning outcomes ($p < 0.05$).
Post-test	Control (Conventional)	25	61.2	69.5	8.3	2.11*	0.045*	The increase was small, but marginally significant ($p < 0.05$).
Independent t-test	Post-test Experiment vs. Control.	25 vs 25	90.8 (Eks)	69.5 (Kon)	21.3	8.95*	0.000	There was a significant difference between the experimental and control classes.

The t-test results showed a significant improvement in the experimental class compared to the control class. The experimental class's pre-test mean score was 61.2, increasing to 90.8 in the post-test, with a difference of 29.6. The t-test yielded a t-count of 12.47 with a significance of $p = 0.000$, confirming a highly significant improvement ($p < 0.05$). In contrast, the control class only experienced an increase from 61.2 to 69.5, a difference of 8.3, with a t-count of 2.11 and $p = 0.045$. Although statistically significant, this increase was relatively small. A direct comparison of the post-test results of the two groups showed an average of 90.8 in the experimental class and 69.5 in the control class. The independent t-test yielded a t-count of 8.95 with $p = 0.000$, indicating a highly significant difference between the two methods. Overall, these data prove that the application of the RME model approach and AR media is more effective in improving learning outcomes than conventional methods.

This study found that combining the Realistic Mathematics Education (RME) approach with Augmented Reality (AR) significantly improved TPE students' basic mathematical understanding. The RME model emphasizes that mathematics is not a set of rigid rules, but rather knowledge derived from real-life experiences. The RME model encourages students to construct meaning, discover patterns, and build mathematical models from situations close to them (Anugraheni et al., 2025). This approach naturalizes the learning process, as students do not simply repeat procedures but learn to connect abstract concepts with concrete reality (Awaji, Khalil, & Al-Zahrani, 2025). AR media complements the principles of the RME model by providing interactive visualizations that bridge the gap between abstract concepts and concrete experiences. Mathematical concepts that are usually difficult to grasp, such as vectors and spatial transformations, can be presented in 3D, which can be rotated, zoomed, and moved (Kit Ng, Tsui, & Yuen, 2022). This research process allows students not only to "imagine" an object but also to interact directly with the digital representation. This reduces cognitive barriers, as

students gain a better multisensory experience. This interactive concept is consistent with multimodal learning theory, which emphasizes the importance of processing information through visual and verbal channels simultaneously (Engelbrecht & Borba, 2024). From a pedagogical perspective, logic-based learning and augmented reality work synergistically (Udeozor, Toyoda, Russo Abegão, & Glassey, 2023). This study found that logic-based learning provides a context-based framework for thinking, while augmented reality enhances this experience through a realistic and immersive medium. When students are asked to solve real-world problems, such as analyzing the motion of objects and measuring distances in space, augmented reality provides images that can be studied directly. Students are guided to formulate symbolic representations and organize them into mathematical models. This process aligns with the principle of guided rediscovery, where students rediscover mathematical concepts through gradual exploration (Hartono, 2025).

The use of Augmented Reality in this study increased students' motivation and curiosity. Learning, which is usually considered static and abstract, became an interactive and challenging experience. Students were encouraged to be more proactive in asking questions, discussing, and experimenting with various solution strategies. This emotional aspect plays a crucial role, as deep understanding is built not only on cognitive abilities but also on emotional engagement in the learning process (Arciniegas-Romero, Narváez-Pinango, Pozo-Revelo, & Álvarez-Tinajero, 2025). Augmented Reality accelerates this process because the visual representations provided demonstrate the relationship between real objects and mathematical symbols. The movement of real-world objects depicted through AR can be directly linked to relevant mathematical equations. This helps students understand that symbols are not just signs, but rather representations of the real phenomena they observe.

In supporting the understanding and thinking skills of TPE students, the collaboration between the RME model and AR media improves analytical, representational, and communicative abilities. Students are encouraged to analyze problems, create models, and then discuss the results with friends. Augmented Reality supports this discussion by providing a shared visual medium, allowing all participants to have a common reference point. This enriches social interactions and encourages the construction of knowledge through dialogue, in line with Vygotsky's sociocultural theory, which emphasizes the role of social interaction in learning (Chen, Li, Zou, Xie, & Wang, 2025). Integrating AR within the RME framework introduces students to new ways to design more contextual, interactive, and effective learning experiences. Students become not only recipients of knowledge, but also practitioners as educators and developers of future learning technologies, capable of bringing innovation into the classroom. The integration of the RME model and AR media supports the improvement of TPE students' understanding through three mechanisms: this integration reduces the distance between mathematical abstraction and reality, thereby facilitating conceptual assimilation. This combination enhances students' cognitive and emotional engagement, which is essential for meaningful learning. The combination of the RME model and AR media trains students to build mathematical representations relevant to real-world contexts, thereby supporting their understanding and improving the learning outcomes and skills of TPE students.

▪ CONCLUSION

The conclusion of this study confirms that the integration of the Realistic Mathematics Education approach with Augmented Reality technology can improve the learning outcomes and literacy of TPE students. The findings indicate that the use of AR-based interactive media not only facilitates conceptual understanding but also fosters active student engagement in the learning process. Thus, this study demonstrates the relevance of implementing immersive technology to strengthen learning effectiveness, particularly in the field of mathematics education. The results obtained provide empirical support for efforts to create contextual, engaging learning that is appropriate to the needs of today's digital generation.

A limitation of this study lies in the sample size of 50 TPE students from a single university. This limits the generalizability of the results, as students at other universities with different backgrounds may exhibit different responses. The designed materials were limited to certain basic mathematical topics, so the effectiveness of the AR-assisted RME model on more complex materials cannot be confirmed. This makes the interpretation of the results only relevant to the scope of the tested materials. The use of AR is highly dependent on specific digital devices, such as mobile phones or tablets with specific specifications. The limited device availability may impact the practicality of implementing the model in the context of other materials, so the results should be interpreted with infrastructure readiness in mind.

The practical implications of this research are to help prospective teachers connect abstract concepts to real-life situations, improving conceptual understanding and mathematical literacy skills. In practice, lecturers can begin learning by presenting contextual problems relevant to everyday life, then guide students through mathematical modeling until they reach an abstract understanding. AR media can be used to provide interactive visual displays, facilitating students' understanding of difficult concepts, and motivating them to learn. This instructional design encourages active participation and critical thinking skills. TPE graduates are expected to be competent teachers in creating meaningful, contextual, and relevant mathematics learning to meet the challenges of the 21st century.

Research recommendations include involving a larger and more diverse number of participants from various universities to obtain more representative results. The implementation of the AR-assisted RME model needs to be tested in various mathematics subjects, including more complex topics, to determine the consistency of its effectiveness. Future research can extend the duration of implementation to determine the long-term impact on students' mathematical knowledge and critical thinking skills. It is necessary to measure lecturers' skills in integrating learning technology to determine its impact on the model's success. The availability and readiness of AR devices in various school environments need to be considered to ensure the resulting solution is more applicable.

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