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MathAR Book Technology Innovation: Effectiveness of Using Augmented Reality-Based Mathematics Books on Students' Mathematical Understanding

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Abstract
Educational innovation continues to develop alongside advances in digital technology, including the use of augmented reality (AR) in learning. This study aimed to examine the effectiveness of an AR-based mathematics book (MathAR Book) in supporting students' mathematical understanding. The study used a one-group pretest–posttest design involving 17 Grade XII students learning probability of events. Data were collected using mathematical understanding tests and a student-interest questionnaire. Students' learning gains were analyzed using normalized gain (N-Gain), while questionnaire responses were summarized as percentages. The reported mean score increased from 20.29 on the pretest to 81.18 on the posttest. The manuscript reports an average N-Gain of 77 and an average student-response percentage of 82.88%, categorized as high according to the criteria presented. The findings indicate improvement in students' test performance following the use of MathAR Book and positive student responses. Because the study involved one class without a comparison group, the results should be interpreted as evidence of improvement in this implementation rather than definitive proof of causal effectiveness.

Keywords: Augmented Reality; Mathematical Understanding; Mathematics Learning; MathAR Book; Student Interest

INTRODUCTION

Mathematical understanding is a fundamental component of mathematics learning because it enables students to interpret mathematical concepts, establish relationships among mathematical ideas, and apply mathematical knowledge to solve problems. Developing such understanding requires learning experiences that go beyond memorizing formulas and performing routine procedures. Students need opportunities to explore mathematical relationships, interpret representations, and connect abstract concepts with meaningful situations. In this regard, instructional resources play an important role in facilitating students' engagement with mathematical ideas and supporting the development of conceptual understanding. Technology-enhanced learning environments have therefore attracted increasing attention as potential means of enriching mathematics instruction and providing alternative ways of presenting mathematical concepts (Bednorz, 2023; Poçan et al.,

2022).

One technology that has received considerable attention in mathematics education is augmented reality (AR), which integrates digital information with the physical environment to create interactive learning experiences. AR can provide visual representations of mathematical objects and relationships that may be difficult to communicate through conventional instructional materials alone. A systematic literature review by Bulut and Borromeo Ferri (2023), which examined 42 studies, identified positive learning outcomes associated with AR implementation in mathematics education, while also discussing its advantages and challenges. Similarly, Erşen and Alp (2024) reviewed 60 studies published between 2012 and 2021 and identified mathematical achievement and students' perceptions of AR applications as prominent research concerns. These reviews suggest that AR represents a promising approach to mathematics instruction, although its educational contribution needs to be evaluated in relation to the specific instructional design, mathematical content, and learning context.

Empirical studies have also investigated the potential of AR to support mathematical learning and students' affective experiences. Elsayed and Al-Najrani (2021) examined the effectiveness of AR in improving visual thinking and academic motivation among middle school students. Poçan et al. (2022) investigated the effects of mobile technology on mathematics learning performance and motivation. More specifically, Cai et al. (2020) integrated three mobile AR applications into probability lessons involving 68 junior high school students. Their findings indicated positive learning gains and student attitudes toward the AR applications. This study is particularly relevant because it demonstrates that the use of AR in probability learning has already received empirical attention. However, AR applications embedded in a sequence of mathematics lessons and AR features integrated into a printed mathematics book represent different instructional formats that warrant consideration in their own right.

Integrating AR into printed books provides one possible approach to connecting conventional reading materials with digital visualization and interaction. Rather than replacing the printed book, this approach supplements its content with digital elements that students can access during learning activities. Previous studies have explored interactive educational books incorporating AR (Abu-Arqoub, 2019), AR-based enrichment books (Anisah et al., 2019), and AR-supported children's books (Ntagiantas, 2022; Wang, 2022). These studies provide a foundation for considering AR-integrated books as a form of technology-enhanced learning resource. Nevertheless, evidence concerning AR applications or interactive books in other educational contexts cannot automatically establish the effectiveness of a particular AR-integrated mathematics book. Its contribution to mathematics learning needs to be examined through implementation-specific evidence.

Despite the growing body of research on AR in mathematics education, further investigation is warranted into how AR-integrated printed mathematics books are implemented and how students respond to these materials in specific mathematical contexts. Existing reviews have documented a range of applications and learning outcomes associated with AR, but they also indicate diversity in the mathematical topics, instructional approaches, and evaluation measures represented in the literature (Bulut & Borromeo Ferri, 2023; Erşen & Alp, 2024). Moreover, although Cai et al. (2020) investigated AR-supported probability lessons, their study focused on mobile AR applications integrated into a series of lessons rather than on the implementation of a printed mathematics book incorporating AR. Accordingly, the present study addresses a context-specific research need by examining MathAR Book as an AR-integrated printed learning resource for probability of events, with attention to both changes in students' mathematical understanding and their responses to the medium. This distinction defines the study's intended contribution without assuming that the broader application of AR to probability learning is unprecedented.

The present study was conducted with Grade XII students at Al Islam Boarding School in Cirebon, Indonesia. It aimed to examine the implementation of MathAR Book in learning probability of events through two research objectives: (1) to describe changes in students' mathematical understanding based on pretest and posttest scores and normalized gain (N-Gain); and (2) to describe students' responses to the use of MathAR Book as a mathematics learning resource. By considering both performance-related outcomes and student responses, this study provides classroom-level evidence regarding the implementation of an AR-integrated mathematics book. Given the one-group pretest–posttest design and the absence of a comparison group, the results are interpreted as changes observed following the implementation rather than definitive evidence that MathAR Book alone caused the observed improvement.

METHODS

The study used a quasi-experimental approach with a one-group pretest–posttest design involving 17 Grade XII students studying probability of events. The class followed the existing classroom arrangement; no separate control group was reported. MathAR Book was developed through the 4D model (Define, Design, Develop, and Disseminate). Media experts, material experts, and practitioners assessed the product, yielding a reported validity level of 85.98%, categorized as eligible. Implementation took place over two meetings, each lasting 90 minutes. Students completed a pretest before instruction and a posttest after learning with MathAR Book, then completed a student-interest questionnaire.

The instruments were a mathematical understanding test and a questionnaire. Learning improvement was analyzed using normalized gain (N-Gain), calculated as the difference between posttest and pretest scores divided by the difference between

the maximum possible score and pretest score. Questionnaire responses were summarized as percentages. The source manuscript does not report instrument reliability, ethical approval, or detailed reverse-scoring procedures.

RESULTS AND DISCUSSION

The manuscript reports an expert/practitioner validity score of 85.98%, categorized as eligible. The media was implemented in the Grade XII class over two 90-minute meetings.

Table 1. Students' mathematical understanding

Measure	Ideal score	Minimum	Maximum	Mean	Standard deviation
Pretest	100	15	30	20.29	5.99
Posttest	100	70	95	81.18	9.11

The reported mean increased from 20.29 to 81.18. The source manuscript reports N-Gain values from 63 to 94, with a mean of 77.

The results presented in Table 1 show an improvement in students' mathematical understanding after the implementation of MathAR Book. The mean pretest score was 20.29, with a minimum score of 15 and a maximum score of 30, indicating that students had relatively low initial performance. After the learning intervention, the mean posttest score increased substantially to 81.18, with scores ranging from 70 to 95. The standard deviation also increased from 5.99 on the pretest to 9.11 on the posttest, suggesting greater variation in students' achievement after the intervention.

Furthermore, the reported N-Gain values ranged from 63 to 94, with an average of 77, indicating a considerable improvement in students' mathematical understanding based on the study's reported results. These findings suggest that the use of MathAR Book may support students in understanding mathematical concepts, particularly in the topic of probability of events. However, since the study employed a one-group pretest–posttest design without a control group, the observed improvement should be interpreted cautiously and cannot be attributed solely to the use of MathAR Book.

Table 2. Descriptive Statistics of Students' N-Gain Scores

N-Gain statistic	Reported value
Minimum	63
Maximum	94
Mean	77

Table 2 presents the descriptive statistics of students' N-Gain scores following the

implementation of MathAR Book. The N-Gain scores ranged from 63 to 94, with a mean score of 77. This average indicates that students experienced a substantial improvement in their mathematical understanding after participating in the learning activities using MathAR Book. The relatively wide range of N-Gain scores also suggests differences in the degree of improvement among students. Overall, these findings indicate that MathAR Book has potential as a learning medium to support the development of students' mathematical understanding, although the results should be interpreted in light of the study's one-group pretest–posttest design. The manuscript reports an average response percentage of 82.88%, categorized as high (76%–100%). The item-level values below are transcribed from Table 3.

Table 3. Student Response

No.	Questionnaire statement (lightly normalized)	Score
1	Practical and flexible; makes learning easier	83.82
2	Book lacks features; respondent does not want to use it	82.35
3	Material is clear and avoids misunderstanding	82.35
4	Feels lazy studying with the book	80.88
5	Can understand concepts using the book	82.35
6	Feels uncomfortable using the book	83.82
7	Needs help learning to use it	80.88
8	Appealing appearance	85.29
9	Material is presented in a complicated way	80.88
10	Encourages harder study	82.35
11	Causes more confusion about probability	83.82
12	Overall satisfaction	80.88

Table 3 presents students' responses to the implementation of MathAR Book, with an overall average response percentage of 82.88%, categorized as high based on the criteria used in the study (76%–100%). The highest score was 85.29% for the statement regarding the attractive appearance of MathAR Book, indicating that its visual design was well received by students. Meanwhile, the lowest score was 80.88%, reported for several statements concerning students' learning experiences, including feeling reluctant to study with the book, needing assistance to use it, perceiving the material as complicated, and overall satisfaction.

The results suggest that students generally responded positively to the use of MathAR Book, particularly in terms of its visual appeal, practicality, and support for understanding mathematical concepts. However, the responses also indicate that some students may still experience difficulties or require additional guidance when using the learning medium. These findings highlight the importance of considering both the design and usability of interactive learning materials to create a more engaging and accessible mathematics learning experience.

Discussion

The increase in the reported mean test score suggests improved performance after the MathAR Book learning sequence. Visual and interactive content may have supported engagement with probability concepts, consistent with literature cited in the manuscript on AR-supported visualization and motivation (Elsayed & Al-Najrani, 2021; Poçan et al., 2022). However, the one-group design cannot isolate the effect of MathAR Book from other factors such as prior instruction or practice effects. The manuscript describes the mean N-Gain of 77 as high, but does not clarify whether the values 63–94 are percentages or decimal-form gain scores. This should be checked against the original calculations. Likewise, several questionnaire items are negatively worded, and the manuscript does not explain whether reverse scoring was applied. This detail is necessary to support the interpretation of the overall response percentage.

The study documents a classroom implementation of MathAR Book for probability-of-events content. Its practical implication is that AR-integrated books may be considered as one option for enriching mathematics instruction, alongside attention to device access and student guidance. Limitations include the small single-class sample, short implementation, and absence of a comparison group. Future studies could use larger samples, comparison conditions, validated instruments, and clearer reporting of calculations.

CONCLUSION

In the participating Grade XII class, the mean mathematical understanding score increased from 20.29 before instruction to 81.18 after two meetings using MathAR Book. The manuscript also reports a mean N-Gain of 77 and an average student-response percentage of 82.88%. These results document improvement and positive responses in this implementation, but do not establish that MathAR Book alone caused the improvement. Further research should verify gain calculations and questionnaire scoring and examine the media with larger and more diverse samples.

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