

Development and Usability of RETEPI: An Augmented Reality Module on Image Formation by Spherical Mirrors for Form 4 Physics

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ABSTRACT

This study focuses on the development and usability study of Realiti Terimbuh Pembentukan Imej Cermin Sfera (RETEPI), an Augmented Reality (AR) learning tool designed to assist Form 4 Physics students in visualizing the complex concepts of Image Formation by Spherical Mirrors. Geometric optics is traditionally challenging due to its reliance on abstract, two-dimensional textbook diagrams that often lead to student misconceptions. To address this, a developmental research design was employed, guided by the ADDIE model, utilizing the MAKAR XR platform to transition static diagrams into interactive 3D learning experiences. The research population comprised 108 Form 4 students, of whom 30 were selected through convenience sampling to participate in the field study, while 15 participated in a preliminary pilot study. Expert validation by two experienced Physics teachers demonstrated a high average validity level of 98%, indicating strong expert agreement on the tool's content accuracy and pedagogical suitability. The pilot study confirmed excellent instrument reliability with a Cronbach's Alpha of 0.905. The field study assessed the tool's usability across three constructs: perceived product usefulness, ease of use, and satisfaction. Quantitative analysis revealed a high overall mean usability score of 4.28 (SD = 0.709), indicating highly positive student feedback. Specifically, the constructs of usefulness (mean = 4.21), ease of use (mean = 4.31), and satisfaction (mean = 4.31) scored exceptionally well. These findings suggest that students perceive RETEPI as an engaging, user-friendly mobile learning tool that effectively supports their conceptual understanding and simplifies complex optical phenomena. Ultimately, RETEPI serves as a highly promising digital intervention that successfully bridges the gap between abstract physics theory and experiential learning.

Keywords: Augmented Reality (AR), Physics Education, Spherical Mirrors, ADDIE Model, Conceptual Understanding

INTRODUCTION

The Ministry of Education Malaysia (KPM) initiated the phased implementation of the Kurikulum Standard Sekolah Menengah (KSSM) in 2017 to align national education with the policy requirements of the Malaysia Education Blueprint (PPPM) 2013-2025 [Thambu & Nadarajan, 2024]. A significant evolution within this framework is the emphasized adoption of technology-based teaching aids to replace or augment conventional methods [Elman et al., 2023]. As contemporary Generation Z students are increasingly drawn to digital environments, the integration of technology in learning sessions has been proven to sustain classroom focus and improve the overall quality of education [Elman et al., 2023]. Among the most prominent technological innovations in modern pedagogy are Augmented Reality (AR) and Virtual Reality (VR). Much like VR, which has been shown to support students' learning of complex scientific phenomena by simulating realistic, interactive environments [Georgiou, 2021], AR significantly assists students in grasping abstract concepts while enhancing interest and academic performance [Kaur et al., 2020], with the added benefit of seamlessly overlaying digital models onto the real-world classroom environment [Abdinejad et al., 2021].

In the era of rapid modernization, Physics is frequently perceived by students as an exceptionally challenging subject, leading to declining examination performance [Mazlan & Abdullah, 2021]. Within the secondary Physics curriculum, students face specific hurdles in mastering optics, particularly the subtopic of image formation by spherical mirrors. This area is notoriously difficult because students are often unable to visualize the three-dimensional process of how light rays behave to form an image. Textbook-based learning alone relies on static, two-dimensional diagrams that cannot fully represent these complex 3D phenomena, leading to widespread misconceptions.

To address these challenges, this study focuses on the development of *Realiti Terimbuh Pembentukan Imej Cermin Sfera (RETEPI)*, an AR-based tool for teaching Image Formation by Spherical Mirrors, and evaluates its usability among Form 4 Physics students. Implementing innovative tools like RETEPI serves as a strategic intervention to bridge the gap between abstract science concepts and experiential learning, aligning directly with the technological demands of modern education [Hendri Adi et al., 2025].

LITERATURE REVIEW

This research is grounded in constructive learning theory and mobile learning theory. Constructive learning theory requires students to engage in activities that shape their view of the world, building upon their existing knowledge with teachers acting as guides rather than passive information dispensers (Bada & Olusegun, 2015). It emphasizes active student involvement through experiments or problem-solving in real-world contexts (Bada & Olusegun, 2015). Immersive digital technologies heavily support this constructivist approach. For instance, studies on immersive VR simulations demonstrate that they extend students' capabilities to collect data and interact with physical phenomena that are otherwise beyond the range of their daily sensory experiences (Georgiou, 2021). The integration of AR in physics classrooms aligns perfectly with these exact principles, providing students the opportunity to construct knowledge through direct, interactive 3D experiences while remaining grounded in their physical learning environment. Systematic reviews of recent educational technologies confirm that AR-based learning media exert a strong positive influence on physics education, especially in visualizing abstract phenomena and reducing cognitive load (Astuti et al., 2024).

Simultaneously, mobile learning theory supports the use of portable devices to facilitate education outside traditional classroom boundaries (Samad et al., 2021). Mobile technologies encourage self-paced revision, effective time management, and flexible access to learning resources (Samad et al., 2021). By leveraging AR through mobile devices, educators can create highly visual, creative, and innovative learning environments. Studies have shown that utilizing AR in physics education significantly enhances student learning achievements and overall engagement compared to traditional methods (Isma et al., 2024; Sholeh et al., 2024; Suprpto et al., 2021). Enhanced visual literacy improves motivation, directly addressing the struggle students face with abstract physics concepts that are difficult to visualize concretely (Kaur et al., 2020).

METHODOLOGY

Research Design

This study employed a developmental research design guided by the five phases of the ADDIE instructional model: Analysis, Design, Development, Implementation, and Evaluation. Quantitative data were collected through surveys to measure perceived usefulness, ease of use, and user satisfaction. The instructional workflow progressed systematically through the five ADDIE phases:

- **Analysis Phase:** Identified student difficulties in visualizing 3D optical phenomena from 2D textbook diagrams, establishing the curricular need for interactive AR models.
- **Design Phase:** Formulated the pedagogical structure, selected core ray diagram scenarios for spherical mirrors, created visual target markers, and adapted the survey instrument.
- **Development Phase:** The complementary RETEPI learning manual was designed using the Canva

platform, leveraging its flexible design tools to integrate clear typography, engaging graphics, and structured learning notes. For the AR simulations, the MAKAR XR platform was selected due to its stability, user-friendliness, and technical reliability, making it ideal for creating accurate 3D visualizations of concave and convex mirrors.

- **Implementation Phase:** Completed expert content validation, executed a pilot study ($n = 15$) to test instrument reliability, followed by the main field evaluation ($n = 30$) in secondary school, Form 4 students.
- **Evaluation Phase:** Analysed quantitative student usability feedback across three core constructs.

Population and Sampling Technique

The population comprised 108 Form 4 students from a secondary school in Malaysia. A pilot study was conducted with 15 students to gather preliminary insights and test the reliability of the instrument. The final research sample for the field study included 30 students selected using convenience sampling technique.

Research Instrument and Scope

The research instruments included an Expert Validity Evaluation Form to confirm face and content validity, and a Usability Questionnaire adapted from Lund's (2001) framework. Reliability was confirmed through the pilot study using Cronbach's Alpha. The Usability Questionnaire contained 15 closed-ended items evaluated on a 5-point Likert scale ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree') (Appendix A). The items were divided across three constructs: Product Usefulness (5 items), Product Ease of Use (5 items), and Product Satisfaction (5 items). It is important to note that the survey measures student-reported perceived usability, ease of operation, and visual engagement rather than direct cognitive achievement gains, as no pre-test/post-test achievement assessment or control group was included in this single-group evaluation.

Expert Validation

Face and content validity were evaluated by an expert validation panel comprising two senior secondary Physics teachers, each with over ten years of active teaching experience in the national KSSM Physics curriculum. The experts reviewed the RETEPI module and evaluation instrument across four dimensions: pedagogical curriculum alignment, scientific accuracy of optical representations, language readability, and practical classroom suitability. The evaluation yielded an average content validity index score of 98% (0.98), confirming strong expert agreement regarding content precision and educational appropriateness.

Instrument Reliability

The pilot study ($n = 15$) confirmed excellent internal consistency for the 15-item instrument, yielding an overall Cronbach's Alpha coefficient of $\alpha = 0.905$ as shown in Table 1. This substantially exceeds the standard threshold of 0.70, establishing high instrument reliability.

TABLE 1. Cronbach's Alpha Reliability Analysis ($n = 15$)

Evaluation Instrument	Sample (n)	Total Items	Cronbach's Alpha (α)
RETEPI Usability Questionnaire	15	15	0.905

RESULTS AND DISCUSSION

Development of RETEPI

To utilize the tool, users download the MAKAR application on their mobile devices alongside the printed RETEPI manual book. By searching the designated ID within the MAKAR app, students can scan the visual AR markers provided in the manual. The application then displays interactive 3D simulations showing the type of mirror, object position, resulting image, light rays, and focal points. It also features gamified AR mini-quizzes that provide immediate visual feedback, reinforcing comprehension. Figure 1 represents the user

interface and outlook of the RETEPI application.

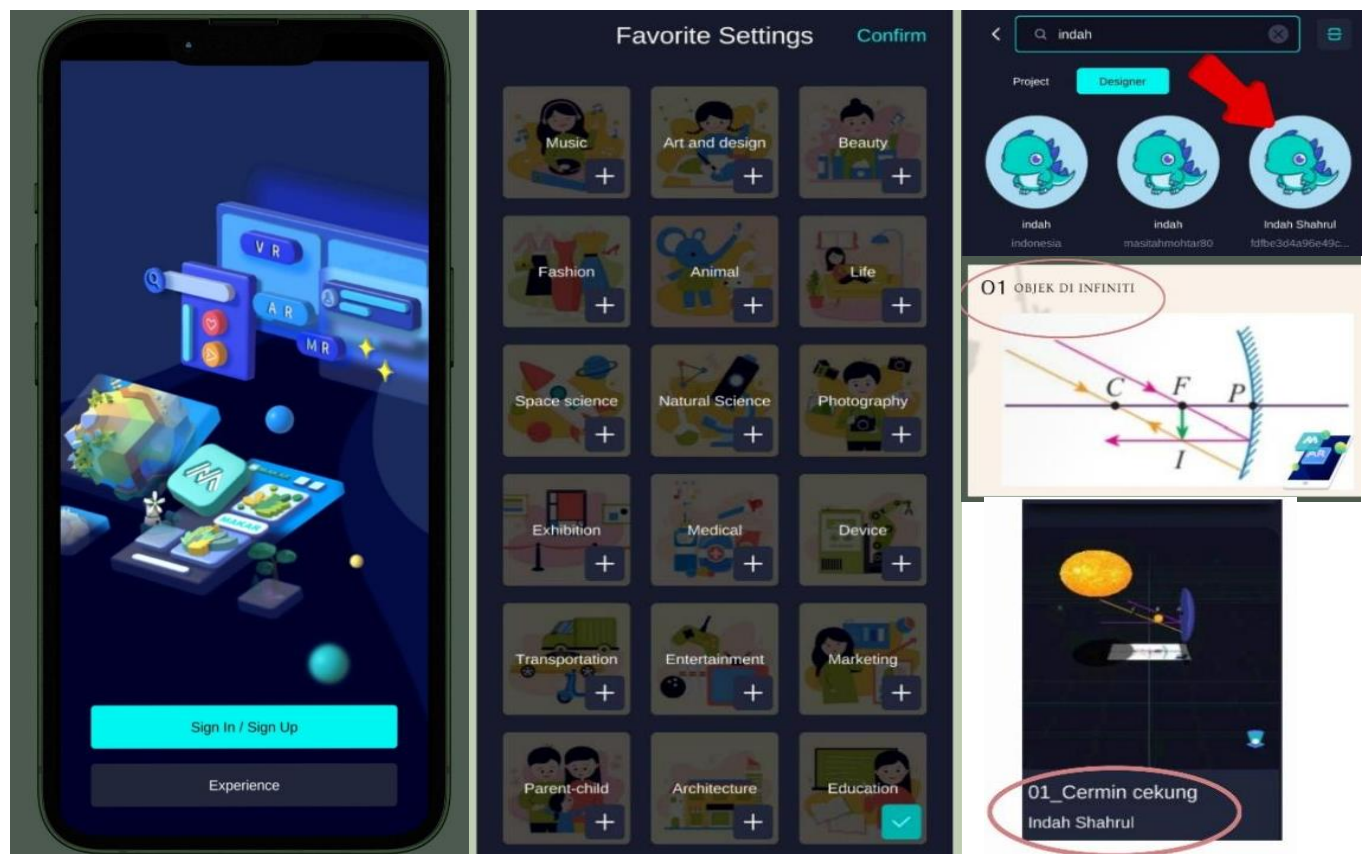


FIGURE 1. The outlook and interface of the RETEPI application

Usability Analysis

The field study evaluated student usability feedback across 30 Form 4 Physics students ($n = 30$). Descriptive statistical analysis executed in SPSS revealed a high overall mean usability score of 4.28 ($SD = 0.709$) on a five (5) point Likert scale. All three evaluated constructs achieved high mean scores above the 3.67 high-usability threshold, as summarized in Table 2.

TABLE 2. Construct-Level Usability Analysis ($n = 30$)

Usability Construct	Items	Mean	Standard Deviation	Interpretation
Usefulness	5	4.21	0.683	High
Ease of Use	5	4.31	0.735	High
Satisfaction	5	4.31	0.708	High
Overall	15	4.28	0.709	High

- Product Usefulness recorded a mean score of 4.21 ($SD = 0.683$). Students indicated that 3D interactive visualizations helped them overcome the visual limitations of static 2D textbook diagrams. A crucial step in learning this topic is for students to visualize how light propagates before and after reflection to form an image. Scanning target markers allowed students to observe 3D ray paths, focal lengths, satisfying visualization needs (Q4) and facilitating comprehension of practical mirror applications (Q5). These findings align with prior research demonstrating that interactive AR visualizations significantly enhance spatial understanding and visual accessibility in physics education (Astuti et al., 2024; Suprpto et al., 2021).
- Product Ease of Use achieved a mean score of 4.31 ($SD = 0.735$). Students highlighted that RETEPI is user-friendly (Q6), operates with simple mobile equipment (Q7), and utilizes clear language (Q8). The

intuitive interface on the MAKAR XR platform allowed students to navigate 3D simulations independently with minimal technical supervision. This supports established mobile learning principles, demonstrating that accessible digital tools promote self-directed learning (Samad et al., 2021).

- Product Satisfaction recorded a mean score of 4.31 (SD = 0.708). High satisfaction ratings reflect student enthusiasm for interactive AR simulations and gamified mini-quizzes. Students noted that RETEPI stimulated learning interest (Q14) and boosted academic motivation (Q15), with a strong willingness to recommend the tool to peers (Q12). These findings reinforce constructivist learning principles (Bada & Olusegun, 2015), confirming that interactive 3D media foster high student engagement (Abdinejad et al., 2021; Kaur et al., 2020).

Overall, these findings confirm that RETEPI is strongly valued by students, demonstrating positive perceptions and a strong potential to facilitate conceptual understanding which robustly supports the constructivist principles of active engagement, contextual problem-solving, and visual literacy (Bada & Olusegun, 2015). Furthermore, demonstrating that AR increases student motivation, which in turn helps them retain and comprehend difficult subjects better, effectively aligning with Education 4.0 and Industrial Revolution requirements (Hendri Adi et al., 2025).

Implications

The findings demonstrate that RETEPI offers meaningful pedagogical and practical contributions to secondary physics education. Pedagogically, RETEPI converts abstract, two-dimensional ray diagrams into tangible, manipulative 3D visualizations, directly targeting common student misconceptions in geometric optics. Practicing teachers can integrate RETEPI as a supplementary learning module to facilitate differentiated instruction and active self-directed learning. Practically, constructing RETEPI on the MAKAR XR platform demonstrates that functional, high-usability AR learning tools can be developed and deployed using accessible, no-code XR platforms without requiring specialized software engineering expertise.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

While the findings demonstrate high perceived usability and student satisfaction, several methodological limitations must be acknowledged. First, the field evaluation was conducted with a convenience sample of 30 Form 4 Physics students from a single secondary school in Malaysia. Consequently, the localized sample limits the external generalizability of the findings to broader regional or national student populations.

Second, the study's research design relied on a post-intervention questionnaire adapted from Lund's (2001) USE framework. Because no pre-test/post-test achievement assessment or quasi-experimental control group was implemented, the findings reflect student-reported engagement and perceived usability rather than objectively measured cognitive achievement gains in geometric optics.

Third, expert content validation was conducted by a two-member panel of senior Physics teachers. Although a high content validity index of 98% was achieved, expanding the validation panel to include instructional technology specialists and university physics educators would further strengthen validation rigor.

To build upon these results, future research should employ quasi-experimental pre-test and post-test control group designs across multiple diverse secondary schools. Combining objective cognitive achievement tests with qualitative student interviews will determine whether the high perceived usability of tools like RETEPI translates directly into measurable academic achievement gains and long-term retention in physics education.

CONCLUSION

An Augmented Reality-based teaching aid, RETEPI, was successfully developed using the MAKAR XR platform and the ADDIE model to transition static 2D diagrams into interactive 3D experiences. The tool achieved a remarkable 98% expert agreement on content validity and an excellent reliability score of 0.905.

The field study revealed a high overall usability score of 4.28 among Form 4 Physics students, confirming that RETEPI is a highly engaging, user-friendly innovation. By effectively bridging the gap between theoretical physics and real-world visualization, RETEPI meets the pedagogical demands of modern education and the Industrial Revolution, transforming how students engage with geometric optics. The results confirm that students perceive RETEPI as an intuitive, highly engaging digital tool that enhances the visual accessibility of abstract optical concepts.

Ethical Considerations

All participants were informed about the purpose of the study, and their consent was obtained prior to participation. No conflicts of interest are declared by the authors.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A: RETEPI USABILITY QUESTIONNAIRE

Adapted from Lund's (2001) USE Questionnaire framework. Evaluated on a 5-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Uncertain, 4 = Agree, 5 = Strongly Agree.

TABLE A1. 15-Item RETEPI Usability Questionnaire

Item	Statement
Q1	RETEPI helps students learn more effectively.
Q2	RETEPI helps students become more productive.
Q3	RETEPI does not require a long time to use.
Q4	RETEPI meets students' needs for visualising spherical mirror image formation.
Q5	RETEPI facilitates understanding of convex/concave mirror applications.
Q6	RETEPI is user-friendly.
Q7	The equipment required is simple and easy to use.
Q8	The wording used in RETEPI is easy to understand.
Q9	RETEPI requires minimal steps to use.
Q10	RETEPI can be used successfully at all times.
Q11	This product meets the expected level of satisfaction.
Q12	Users would recommend this product to their peers.
Q13	This product functions in the way users expect it to.
Q14	This product interests students in learning spherical mirror image formation.
Q15	Using this product for learning makes students more motivated to learn.