

Design and Development of a Dual-Mode Mobile Augmented Reality Learning System for 3D Modeling Education

Ning Yueqin¹, Nur Azlina Mohamed Mokmin^{2*}, Yan Ju³

1,2,3 Centre for Instructional Technology and Multimedia, Universiti Sains Malaysia, Penang 11800, Malaysia

ORCID: ¹<https://orcid.org/1669-1678-1669-1678>; ²<https://orcid.org/1669-1678-1669-1678>;

³<https://orcid.org/1669-1678-1669-1678>, Email: ¹yueqin@student.usm.my; ²nurazlina@usm.my;

³yanju@student.usm.my

Corresponding author: Nur Azlina Mohamed Mokmin*

HOW TO CITE:

Ning Yueqin, Nur Azlina
Mohamed Mokmin, Yan Ju (2026).
Design and Development of a
Dual-Mode Mobile Augmented
Reality Learning System for 3D
Modeling Education.
International Journal of Special
Education, 41(22s), 1669-1678

COPYRIGHT STATEMENT:

Copyright: © 2026 Authors.
Open access publication under the
terms and conditions
of the Creative Commons Attribution
(CC BY)
license (<http://creativecommons.org/licenses/by/4.0/>).

ABSTRACT:

3D modeling education requires learners to coordinate complex software operations, multi-step procedures, and spatial understanding, yet conventional instruction may not adequately support both guided skill acquisition and independent exploration. This study designed and iteratively refined GEM, a dual-mode mobile augmented reality learning system that integrates these forms of support. Using Design and Development Research organized through the ADDIE model, a needs analysis of 58 Digital Media Technology students informed system requirements. Graduated Difficulty Learning Strategy and Exploratory Learning Strategy were operationalized as the GEM-AR-GRAD and GEM-AR-EXPLOR modes. The system was evaluated by four experts, tested on five Android devices, and formatively tested with eight target students. Core functions operated successfully, experts provided generally positive evaluations, and the median student-level mean score was 4.46. Feedback from experts and students informed two rounds of refinement. The study provides a design-based example of integrating graduated guidance and exploratory support as distinct learning modes within a shared mobile AR task architecture, offering practical guidance for the design and formative refinement of AR-supported 3D modeling education.

Keywords: mobile augmented reality, 3D modeling education, design and development research, graduated difficulty learning strategy, exploratory learning strategy.

1. Introduction

3D modeling is an important practical course in fields such as Digital Media Technology, animation, game design, and virtual reality. Learners need not only to master complex software operations but also to understand spatial structures, geometric relationships, and multi-step modeling procedures, and to apply this knowledge in the creation of complete works. Previous studies have shown that spatial visualization and reasoning abilities play an

important role in learning tasks that involve understanding three-dimensional objects, and spatial ability is also closely related to computer-aided design learning (Abdo et al., 2024; Bartlett & Camba, 2024). At the same time, multi-step operations in complex software may further increase learning difficulty (Darejeh et al., 2022). Therefore, 3D modeling education needs learning resources that can continuously support software operation, spatial observation, and the completion of practical tasks.

In 3D modeling classes that mainly rely on teacher-led demonstrations and standardized learning resources, students usually follow the same learning pace. It is difficult for them to repeatedly review key operational steps according to their own needs, and they may also have difficulty continuously observing how model structures change across different modeling stages. Structured guidance can help students understand complex operational sequences, while observation, analysis, and trial provide another form of learning support for understanding model structures and carrying out independent problem solving. Therefore, a single form of resource presentation and learning support may not be able to meet both the need for procedural guidance and the need for autonomous exploration.

Mobile augmented reality (AR) can present videos, images, and interactive 3D objects through smartphones in real learning environments. This allows learners to repeatedly access learning resources and understand complex structures through rotation, zooming, and viewing from different angles. Previous studies and systematic reviews have shown that AR has the potential to support visualization, interaction, learner-centered activities, and information access in educational settings, and it has been applied in engineering and practical skills learning (Alzahrani, 2020; Suhail et al., 2024; Waskito et al., 2024). However, the educational value of AR does not come automatically from the technology itself. Its use may also be influenced by factors such as cognitive load, technical complexity, and instructional design (Alzahrani, 2020; Gonnermann-Müller & Krüger, 2025). Therefore, the key issue in mobile AR system design is not simply to add videos or 3D models, but to integrate technological functions with clear forms of instructional support.

Structured guidance and autonomous exploration provide complementary forms of support for complex skill learning. GDLS organizes tasks from simple to complex and provides step-by-step resources (Mokmin & Masood, 2014), whereas ELS in this study emphasizes active

observation, analysis, trial, and correction. Exploration nevertheless requires appropriate guidance and scaffolding (de Jong et al., 2023). Although previous mobile AR studies have incorporated interactive 3D objects and digital learning resources (Samala et al., 2024; Suhaizal et al., 2023; Waskito et al., 2024), limited attention has been given to integrating specific instructional strategies with shared learning objectives and technological environments (Gil Parga et al., 2024). It therefore remains unclear how structured guidance and model exploration can be operationalized as two distinct mobile AR learning modes within the same system.

Based on these issues, this study adopted Design and Development Research (DDR) as the overall approach and used the ADDIE model to organize the development process (Richey & Klein, 2014; Spatioti et al., 2022). Following an analysis of vocational undergraduate students' difficulties and support needs in 3D modeling, the study developed GEM, a dual-mode mobile AR learning system that operationalized GDLS and ELS as the GRAD and EXPLOR modes, respectively. The two modes shared learning objectives, modeling tasks, the mobile AR environment, and evaluation criteria but differed in resource format, scaffolding, and learner control. Expert evaluation, Android-device testing, and formative testing with target students supported iterative system refinement. The study focused on system design, development, functional feasibility, and initial usability; it did not compare the learning effects of the two modes or match learning modes to learner ability.

Accordingly, the study addressed the following research questions:

RQ1: What mobile AR system design requirements were identified from students' 3D modeling learning needs?

RQ2: How were GDLS and ELS transformed into two mobile AR learning modes in the GEM system?

RQ3: What problems in the GEM system were identified through expert evaluation, technical testing, and formative evaluation with target

students, and how did these evaluation results support the iterative refinement of the system?

2. Methodology

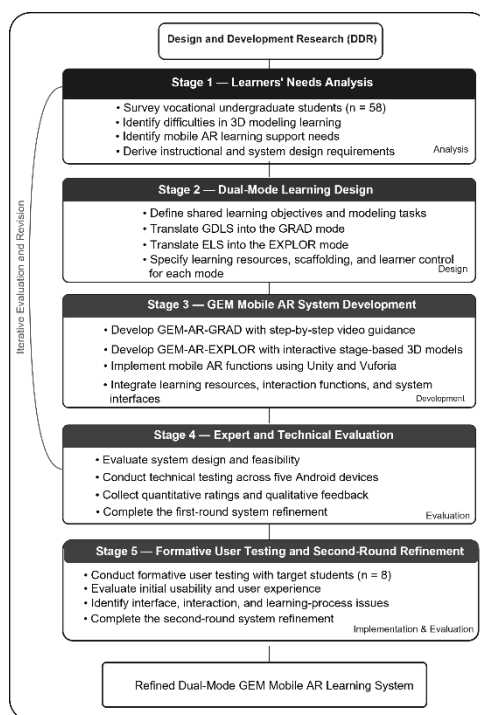
2.1 Research Design and Development Procedure

This study adopted Design and Development Research (DDR) as the overall research approach to guide the systematic needs analysis, design, development, and formative evaluation of the GEM mobile AR learning system. DDR was appropriate because it focuses not only on developing educational products but also on improving their design through continuous evaluation and revision (Richey & Klein, 2014). Within this framework, the ADDIE model organized the development activities across the Analysis, Design, Development, Implementation, and Evaluation stages, connecting learner needs,

instructional design, technical implementation, and evaluation-based refinement (Spatioti et al., 2022).

As shown in Figure 1, the research process comprised five connected stages. First, the learner needs analysis identified students' major difficulties in 3D modeling and their needs for mobile AR learning support. Second, the findings were translated into system design requirements, and the GRAD and EXPLOR modes were designed around shared learning objectives and modeling tasks. Third, these designs were implemented in the GEM mobile AR system. Fourth, expert evaluation and technical testing on Android devices informed the first round of revision. Fifth, formative testing with target students supported a second round of refinement, after which the dual-mode GEM system was finalized.

Figure 1. Research Design and Development Procedure of the GEM System



2.2 Participants, Instruments, and Data Collection

This study was conducted in a 3D modeling course within the Digital Media Technology program at a vocational undergraduate institution in southern China. Data collection corresponded to the design, development, and formative

evaluation process of the GEM system and mainly included a learner needs survey, expert evaluation, technical testing on Android devices, and formative user testing with target students. Different data sources and evaluation tools were used at different stages to support the identification of system design requirements,

system function checking, and subsequent iterative refinement.

The learner needs survey involved Digital Media Technology students who were currently taking or had previous basic learning experience in 3D modeling. A total of 58 students participated and completed valid questionnaires. A researcher-developed 5-point Likert questionnaire was used to examine students' 3D modeling learning experience, learning difficulties, needs for structured guidance and autonomous exploration, and acceptance of mobile AR learning support. The survey results were used to identify the main learning needs of the target learners and were further translated into design requirements for the GEM system. Modeling proficiency reported in the questionnaire was used only as background information and was not used for ability diagnosis or to determine whether students should use the GRAD or EXPLOR mode.

After the initial version of the system was completed, four experts were invited through purposive sampling to conduct formative evaluation. The expert group included two experts in 3D modeling or digital media content and two experts in instructional design. The content experts used a 15-item, 5-point Likert evaluation form to assess learning tasks, course objectives, task difficulty, strategy presentation, AR content, and the appropriateness of instructional implementation. The instructional design experts used a 13-item, 5-point Likert evaluation form to assess system stability, model interaction, module structure, task flow, interface design, operational prompts, and mobile device adaptation. Both groups of experts also provided open-ended comments to identify issues that required further revision. At the same time, technical testing was conducted on five Android smartphones to check system installation and startup, AR recognition, 3D model loading and operation, module navigation, video playback, page display, and system stability. The results of the expert evaluation and technical testing were used together for the first round of system revision.

After the first revision, eight target students were purposively selected for formative testing, with four using GRAD and four using EXPLOR. During standardized 45-minute sessions, navigation, AR recognition, media playback, model interaction, and task understanding problems were recorded. Students then completed a 12-item Likert evaluation and open-ended questions. The testing was intended to identify initial usability issues, not to compare the learning effects of the two modes.

Ethical approval for this study was granted by the Human Research Ethics Committee of Universiti Sains Malaysia. Informed consent was obtained from all participants before data collection.

2.3 Data Analysis

Descriptive analysis was used according to the type of data collected at each stage of the study. Data from the needs survey of 58 students were summarized using frequencies and percentages. The analysis mainly focused on students' difficulties in 3D modeling learning, their needs for structured guidance and autonomous exploration, and their acceptance of mobile AR learning support. The results were further organized into a mapping of "learning needs–system design requirements–system functions" to show how learners' needs were translated into specific design requirements for the GEM system.

Expert evaluation data were described using mean scores for each evaluation dimension, together with open-ended feedback to identify issues that required system revision. Technical testing on Android devices was analyzed based on whether each function operated as expected and on the problems recorded during testing. For each student, a mean score across the 12 evaluation items was first calculated. The formative evaluation data were then summarized using the median of the eight student-level mean scores and the frequencies of the 96 individual item responses. Because of the small sample size, no between-group significance tests were conducted. Open-ended feedback from experts and students was organized into categories such

as task flow, mode differentiation, navigation, interaction, resource presentation, AR recognition, and system stability, and was linked to the corresponding system revisions. These analyses were used to support system design and formative refinement rather than to infer the learning effectiveness of the GEM system.

3. Results

3.1 Learner Needs and Design Requirements

The 58 valid questionnaires identified learners' major difficulties, support needs, and acceptance of mobile AR. The needs analysis showed that the main difficulties students faced in 3D modeling learning were a lack of clear guidance (65.52%) and complex software operations (60.34%). In addition, 32.76% of the students considered the modeling tasks to be complex, while 31.03% wanted more opportunities for autonomous exploration. These results show that students reported needs for both operational guidance and opportunities for autonomous exploration.

Regarding learning strategy preferences, approximately 70% of the students preferred a clear, step-by-step learning approach, approximately 63% agreed that independent exploratory learning could support their understanding of modeling knowledge, and

approximately 75% were willing to try different learning strategies, including progressive guidance and independent exploration. Based on these needs, GEM provides both GRAD and EXPLOR learning support modes under shared learning objectives and task structures, rather than assigning students to a fixed mode based on their ability. Regarding mobile AR, approximately 64% of the students were willing to try an AR learning system, 62% agreed that AR could support their understanding of modeling structures and operations, and 67% believed that AR could increase their interest and engagement in modeling.

Based on the needs analysis, four system design requirements were identified: (1) a progressive task structure from basic operations to comprehensive modeling; (2) clear and repeatable operational guidance; (3) support for 3D model observation, autonomous analysis, and learner control; and (4) two forms of learning support within shared learning objectives, core tasks, and a mobile AR environment. These requirements were translated into specific GRAD and EXPLOR functions, establishing the mapping between learner needs, design requirements, and system implementation shown in Table 1.

Table 1. Mapping of Learner Needs, System Design Requirements, and GEM System Implementation

Learner Needs Analysis Findings	System Design Requirements	GEM System Implementation
Lack of clear guidance (65.52%); complex software operations (60.34%)	Provide clear and repeatable procedural guidance.	Step-by-step AR videos; predefined sequence; operational prompts
Need for autonomous exploration (31.03%)	Support model observation, analysis, and learner control	Rotatable, zoomable staged 3D models
Different levels of prior modeling experience	Provide a task structure progressing from basic operations to more comprehensive modeling tasks.	Basic, intermediate, and comprehensive modeling tasks are provided, but task difficulty is not used to automatically assign learners to a learning mode.

Approximately 75% of the students were willing to try different learning strategies, including progressive guidance and independent exploration.	Provide two forms of learning support under shared learning objectives and tasks.	GEM provides both GRAD and EXPLOR learning modes within the same learning environment.
Positive attitudes toward mobile AR: willingness to try (approximately 64%), perceived support for understanding (approximately 62%), and increased interest and engagement (approximately 67%).	Provide a mobile, visual, and interactive AR learning environment.	Android smartphones are used to present AR videos, 3D models, and interactive learning resources.

3.2 Dual-Mode Design and Development of the GEM System

GEM operationalized GDLS and ELS as the GRAD and EXPLOR modes, respectively. Both

modes shared the learning objectives, modeling tasks, task structure, mobile AR environment, and evaluation criteria but differed in resources, sequencing, scaffolding, and learner control, as summarized in Table 2.

Table 2. Design Characteristics of the GRAD and EXPLOR Modes

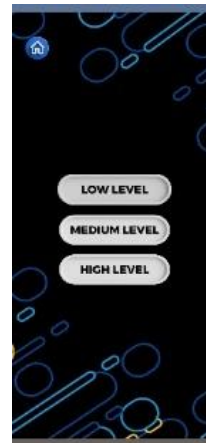
Design Dimension	GEM-AR-GRAD	GEM-AR-EXPLOR
Learning objectives	Shared learning objectives	Shared learning objectives
Modeling tasks	Shared modeling tasks	Shared modeling tasks
Task structure and difficulty	Shared task structure and difficulty	Shared task structure and difficulty
Mobile AR environment	Shared Android-based AR environment	Shared Android-based AR environment
Primary learning resource	Step-by-step AR instructional videos	Interactive staged 3D models
Learning sequence	Predetermined and sequential	Flexible and exploratory
Scaffolding	Higher; step-by-step guidance and operational prompts	Moderate; task goals, stage labels, and essential prompts
Learner control	Lower; learning follows a predefined sequence	Higher; learners control model observation and exploration
Main interaction	Video viewing, pausing, replaying, and step navigation	Model rotation, zooming, stage switching, and multi-angle viewing

GEM was developed in Unity and integrated with Vuforia for image-target-based mobile AR. The system incorporated task navigation, instructional videos, staged 3D models, and interactive functions and was deployed on Android devices (Figure 2). GRAD supported

sequenced video guidance and step navigation, whereas EXPLOR supported stage switching, model rotation, zooming, and multi-angle observation. These interfaces demonstrate how the two forms of learning support were implemented in the system.

Figure 2. Key Interfaces of the Dual-Mode GEM Mobile AR System

(a) Task difficulty selection-GRAD



(b) Task difficulty selection-EXPLOR



(c) GEM-AR-GRAD



(d) GEM-AR-EXPLOR

3.3 Formative Evaluation and System Refinement

Two rounds of formative evaluation identified instructional, technical, and usability problems and linked them to corresponding system revisions. The first round of evaluation was completed by four experts, including two 3D modeling content experts and two instructional design experts. Overall, all evaluation dimensions received relatively high scores. The content experts gave a mean score of 5.00 for content accuracy and appropriateness and 4.75 for task organization and progression of difficulty. The instructional design experts gave mean scores of 4.67 for GRAD, 4.90 for EXPLOR, and 4.83 for the overall instructional design. Expert feedback mainly focused on the clarity of learning instructions, the distinction between the two modes, task-stage prompts, and the presentation of some interface information. Based on this feedback, the learning instructions, mode

prompts, stage labels, and related interface content were further refined.

The system was then technically tested on five Android devices with different hardware configurations. The results showed that the core system functions were able to operate, although some issues were identified in AR recognition, resource presentation, and the stability of certain interactions. These functions were revised and retested to confirm that the system could support the subsequent target-user testing.

The second round of formative evaluation involved eight target students, with four using GEM-AR-GRAD and four using GEM-AR-EXPLOR. Overall, the students gave positive evaluations. The median of the eight students' individual mean scores across the 12 evaluation items was 4.46, and 94 of the 96 individual item responses (97.9%) were rated 4 or 5. Open-ended feedback showed that some students still experienced difficulties with page navigation, prompts, AR recognition, and interactive

operations. Based on this feedback, the operational prompts, page navigation, learning-stage identification, AR resource access, and selected interactive functions were further improved, completing the second round of system revision. After two rounds of formative evaluation and refinement, GEM was finalized with two mobile AR learning modes, GRAD and EXPLOR, under a shared task structure.

4. Discussion

4.1 From Learner Needs to System Design

The needs analysis established an instructional basis for GEM by linking reported difficulties—particularly complex operations and insufficient guidance—to repeatable resources, interactive 3D visualization, and learner-controlled access. This needs-driven process is important in software-intensive learning, where instructional support must correspond to task demands (Darejeh et al., 2022). It also reflects evidence that the educational value of AR depends on decisions concerning guidance, interaction, content, and display rather than on the technology alone (Gonnermann-Müller & Krüger, 2025). The contribution of the needs analysis therefore lies in translating learner difficulties into explicit system requirements and functions.

4.2 Designing Dual-Mode Learning Support in Mobile AR

The dual-mode design of GEM provides different forms of learning support within a shared instructional environment. Both modes maintain the same learning objectives, modeling tasks, task structure and difficulty, technological environment, and evaluation criteria while varying how learning support is provided. This design separates what learners are expected to complete from how the system supports task completion, allowing structured guidance and exploratory support to coexist within the same mobile AR environment.

Rather than treating structured guidance and exploratory learning as mutually exclusive, GEM represents them as different forms and degrees of instructional support. de Jong et al. (2023) emphasized that inquiry-based learning requires

appropriate guidance and scaffolding rather than minimal guidance. Accordingly, GRAD provides stronger procedural scaffolding through sequenced resources and operational prompts, whereas EXPLOR gives learners greater control over model observation and exploration while retaining clear task boundaries and essential support. EXPLOR therefore represents guided exploration rather than unguided discovery.

Learning-support mode and task difficulty were also treated as independent design dimensions. Task difficulty determines the complexity of the modeling activity, whereas the selected mode determines how learning support is presented. GEM therefore neither assigns learning modes according to learner proficiency nor assumes that one mode is generally superior. Its contribution lies in demonstrating how support with different instructional characteristics can be implemented within a shared mobile AR system, an approach that may also inform other practice-based learning environments.

4.3 Formative Evaluation, Practical Implications, and Limitations

Formative evaluation functioned as an iterative mechanism for identifying instructional, technical, and usability problems that were not fully recognized during initial development. Expert evaluation, Android-device testing, and target-student testing provided complementary evidence and supported two rounds of system revision. This multi-source process reduced reliance on the developers' judgment and enabled design decisions to be revised in response to formative evidence. The resulting cycle of design, development, evaluation, and revision reflects the iterative improvement emphasized in Design and Development Research (Richey & Klein, 2014; Spatioti et al., 2022; Tinoca et al., 2022).

Practically, GEM demonstrates that mobile AR can serve not only as a medium for presenting digital resources but also as an environment for implementing different forms of instructional support. By varying resource format, learning sequence, scaffolding, and learner control while maintaining shared objectives and modeling

tasks, teachers and educational technology developers can support different learning processes without developing separate course content or technological environments for each mode.

Several limitations should be considered. First, GEM was developed for one vocational undergraduate 3D modeling course, limiting the generalizability of the findings to other disciplines, institutions, and learner groups. Second, formative testing involved only eight students and was intended to identify initial usability and interaction problems rather than establish learning effectiveness. Third, testing on five Android devices cannot demonstrate compatibility with all hardware and operating-system configurations. Finally, the study neither compared the learning effects of GRAD and EXPLOR nor examined relationships between learner characteristics and learning outcomes. Future studies should evaluate the system with larger samples, additional devices and learning contexts, and controlled designs that examine the learning processes and outcomes associated with the two modes.

5. Conclusion

This study designed and developed the dual-mode GEM mobile augmented reality learning system based on the practical needs of vocational undergraduate 3D modeling learning. Design and Development Research (DDR) was adopted as the overall research approach, and the ADDIE model was used to organize the system development process. The results of the needs analysis were further translated into system design requirements, and GDLS and ELS were implemented as two learning support modes, GRAD and EXPLOR, respectively. The two modes shared the same learning objectives, modeling tasks, task structure, and mobile AR environment, but differed in learning resources, learning sequence, level of scaffolding, and

learner control, forming a dual-mode learning support design within a shared task architecture.

Expert evaluation, technical testing on Android devices, and formative testing with target students supported two rounds of system refinement and provided formative evidence for the instructional design, technical operation, and initial usability of GEM. The main contribution of this study is to show how different forms of instructional support can be implemented as operational modes within the same mobile AR system, rather than automatically matching learning paths according to learner proficiency. Because this study did not compare the learning effects of GRAD and EXPLOR, the current findings cannot determine whether one mode is more effective than the other. Future research may further examine the effects of the two learning support modes on learning processes and learning outcomes with larger samples and in more authentic classroom settings.

6. Author Declaration

The authors confirm that this manuscript is an original work and has not been published elsewhere or submitted simultaneously to another journal. The authors declare that there are no conflicts of interest related to this study. Ethical approval for this study was obtained from the Human Research Ethics Committee of Universiti Sains Malaysia (JEPeM-USM; Approval No. USM/JEPeM/PP/26040323) on 21 August 2026. Informed consent was obtained from all participants involved in the study.

Author Contributions. Ning Yueqin was primarily responsible for the study design, system development, data analysis, and original drafting. Nur Azlina Mohamed Mokmin supervised the study and contributed to the methodology and manuscript revision. Yan Ju contributed to the methodology, data analysis, and manuscript revision. All authors reviewed and approved the final manuscript.

References

- Abdo, S. N., Hsu, J. L., Kapetanakis, C., Newman, D. L., Wright, L. K., & Bailey, J. (2024). An exploration of spatial visualization skills: Investigating students' use of 3D models in science problems during think-aloud interviews. *Journal of Chemical Education*, 101(9), 3624–3634. <https://doi.org/10.1021/acs.jchemed.3c01355>
- Alzahrani, N. M. (2020). Augmented reality: A systematic review of its benefits and challenges in e-learning contexts. *Applied Sciences*, 10(16), 5660. <https://doi.org/10.3390/app10165660>
- Bartlett, K. A., & Camba, J. D. (2024). Toward a broader understanding of spatial ability in CAD education. *Computer-Aided Design and Applications*, 21(1), 39–54. <https://doi.org/10.14733/cadaps.2024.1669-1678>
- Darejeh, A., Mashayekh, S., & Marcus, N. (2022). Cognitive-based methods to facilitate learning of software applications via e-learning systems. *Cogent Education*, 9(1), 2082085. <https://doi.org/10.1080/2331186X.2022.2082085>
- de Jong, T., Lazonder, A. W., Chinn, C. A., Fischer, F., Gobert, J., Hmelo-Silver, C. E., Koedinger, K. R., Krajcik, J. S., Kyza, E. A., Linn, M. C., Pedaste, M., Scheiter, K., & Zacharia, Z. C. (2023). Let's talk evidence—*The case for combining inquiry-based and direct instruction*. *Educational Research Review*, 39, 100536. <https://doi.org/10.1016/j.edurev.2023.100536>
- Gil Parga, S., Singh, U., Gutierrez, J., & Marks, S. (2024). Pedagogical design in education using augmented reality: A systematic review. *Interactive Learning Environments*, 32(8), 4219–4236. <https://doi.org/10.1080/10494820.2023.2195445>
- Gonnermann-Müller, J., & Krüger, J. M. (2025). Unlocking augmented reality learning design based on evidence from empirical cognitive load studies—A systematic literature review. *Journal of Computer Assisted Learning*, 41(1), e13095. <https://doi.org/10.1111/jcal.13095>
- Mokmin, N. A. M., & Masood, M. (2014). Development of multimedia learning application for mastery learning style: A graduated difficulty strategy. *International Journal of Business, Human and Social Sciences*, 8(12), 3909–3912. <https://scholarly.org/pdf/display/development-of-multimedia-learning-application-for-mastery-learning-style-a-graduated-difficulty-strategy>
- Richey, R. C., & Klein, J. D. (2014). Design and development research: Methods, strategies, and issues. Routledge. <https://doi.org/10.4324/9780203826034>
- Samala, A. D., Howard, N.-J., Criollo-C, S., Budiman, R. D. A., Hakiki, M., & Hidayah, Y. (2024). What does an IMoART application look like? IMoART—An interactive mobile augmented reality application for support learning experiences in computer hardware. *International Journal of Interactive Mobile Technologies*, 18(13), 148–165. <https://doi.org/10.3991/ijim.v18i13.47565>
- Spatioti, A. G., Kazanidis, I., & Pange, J. (2022). A comparative study of the ADDIE instructional design model in distance education. *Information*, 13(9), 402. <https://doi.org/10.3390/info13090402>
- Suhaizal, H., Abdul Rahman, K. A., Khamis, N., Shukor, U. H., Che Lah, N. H., & Zulkifli, N. N. (2023). The design and development of augmented reality (AR) application for internet evolution learning topics. *International Journal of Interactive Mobile Technologies*, 17(5), 162–181. <https://doi.org/10.3991/ijim.v17i05.36483>
- Suhail, N., Bahroun, Z., & Ahmed, V. (2024). Augmented reality in engineering education: *Enhancing learning and application*. *Frontiers in Virtual Reality*, 5, 1461145. <https://doi.org/10.3389/frvir.2024.1461145>
- Tinoca, L., Piedade, J., Santos, S., Pedro, A., & Gomes, S. (2022). Design-based research in the educational field: A systematic literature review. *Education Sciences*, 12(6), 410. <https://doi.org/10.3390/educsci12060410>
- Waskito, Fortuna, A., Prasetya, F., Wulansari, R. E., Nabawi, R. A., & Luthfi, A. (2024). Integration of mobile augmented reality applications for engineering mechanics learning with interacting 3D objects in engineering education. *International Journal of Information and Education Technology*, 14(3), 354–361. <https://doi.org/10.18178/ijiet.2024.14.3.2057>
-