Integration of an Augmented Reality Application into a Learning System Based on Kolb's Experiential Learning Model

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Abstract

Students' learning motivation often decreases when the learning method does not align with their individual learning styles, posing a challenge for effective and meaningful education. Augmented Reality (AR) technology offers an interactive solution to increase student engagement. This study aims to develop an AR-based learning system adapted to Kolb's learning styles: Diverger, Assimilator, Converger, and Accommodator, to support personalized and enjoyable learning. The system was developed using the ADDIE model and an object-oriented approach. Evaluation involved black box testing and user testing based on the Technology Acceptance Model (TAM). Results showed over 80% of students were satisfied with the application, 75% found learning more interesting, and approximately 70% demonstrated increased active participation. TAM analysis revealed an average score of 80.26 and a positive correlation between perceived ease of use and motivation. The application encourages deeper exploration of material and boosts students' confidence in facing academic challenges. In conclusion, the developed system effectively supports technology-based personalized learning. Its implication suggests that AR integration in education can enhance learning quality and serve as a foundation for future intelligent systems incorporating artificial intelligence.

INTRODUCTION

Current challenges in education are not only related to the availability of learning technology, but also to how such technology can create a more interactive, personalized, and immersive learning experience. In practice, traditional classroom learning has increasingly adopted learning technologies, such as digital presentations, videos, and learning management systems. However, these technologies are often still static, less interactive, and unable to fully provide an immersive learning experience for students.

On the other hand, the development of information and communication technology (ICT) provides opportunities to create more visual, interactive, and immersive learning environments. One of the technologies that supports this need is Augmented Reality (AR), as it can integrate virtual objects into the real environment in an interactive way. This technology allows students to experience more concrete learning through 3D object visualization, virtual exploration, and direct interaction with learning materials. AR technology has been shown to increase student learning motivation, especially in terms of attention, self-confidence, and comfort in the learning process [1]-[3]. In addition, AR

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provides a learning experience that is in accordance with constructivist learning theory, which emphasizes the importance of physical and social contexts in the learning process and supports activities such as inquiry, active observation, and collaborative learning [4],[5].

However, traditional classroom learning still assumes that all students have the same characteristics, so teachers usually use uniform learning methods and materials [6]. In fact, each student has a different learning style, as explained in Kolb's theory, which divides learning styles into Diverger, Assimilator, Converger, and Accommodator [7]. The mismatch between learning methods, students' learning styles, and the limited immersive experience in the learning process can reduce students' motivation and learning effectiveness. Therefore, a more personalized, adaptive, interactive, and immersive learning approach is needed.

Several previous studies have developed AR-based learning systems that are tailored to students' learning styles to improve engagement and learning outcomes [8]-[13]. For example, several studies have shown that AR integration with a personalization approach can significantly improve motivation and conceptual understanding [11]-[12]. However, most of these studies still face obstacles in implementing easy-to-use technology and system scalability in real learning contexts.

Previous studies have shown that although AR and personalized learning are promising, there are not many systems that optimally combine Kolb's learning style model with AR technology in a complete virtual learning environment with an interactive 3D interface. In addition, the evaluation of technology acceptance from the user's perspective (e.g. using the Technology Acceptance Model/TAM) has also not been studied in depth to ensure the success of the system implementation.

The use of TAM in educational technology research is important because the success of a learning system is determined not only by its technical features, but also by how users perceive its usefulness and ease of use. Recent studies have applied TAM to test the acceptance of various educational technologies, including ChatGPT in ubiquitous learning environments, social media technology for learning during the COVID-19 pandemic, intelligent physical education systems, educational management applications in madrasah environments, and Duolingo as a language learning application [14]-[18]. These studies indicate that TAM is relevant for evaluating users' perceptions, attitudes, and behavioral intentions toward technology-based learning systems.

Therefore, this study aims to develop an AR-based learning system that is tailored to students' learning styles according to the Kolb model in a virtual environment with a 3D interface. This system was developed using the ADDIE model and evaluated through user trials using the TAM framework to measure acceptance and its impact on students' learning motivation. It is hoped that this study can contribute to the development of effective and enjoyable personal learning technology and become the basis for the development of intelligent systems in the future.

LITERATURE REVIEW

Augmented Reality

Augmented Reality (AR) is a variant of virtual reality [19]. AR technology opens up new ways to interact between the real and virtual worlds [20]. AR aligns actual and virtual objects with each other and enhances the virtual experience based on dynamic 3D objects. In AR, users are aware of their surroundings while interacting with AR applications and the added virtual content.

The rise of augmented reality (AR) has generated considerable interest in its potential to revo-lutionize the educational landscape. Beyond its inherent novelty, AR's capacity to create interac-tive and captivating interfaces offers a unique opportunity to infuse a natural allure into the learning experience [21],[22]. This captivating technology goes beyond the constraints of con-ventional learning tools, seamlessly integrating with desktops, tablets, smartphones, and even immersive Head-Mounted Displays (HMDs). Moreover, the portability and adaptability of AR make it a versatile tool, capable of

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enhancing the learning process in various settings. Whether in the traditional classroom, the specialized environment of special education, or beyond the class-room walls, AR's transformative potential can be leveraged to enrich learning in diverse contexts [23].

Traditional teaching methods largely depend on text and two-dimensional (2D) images, which can limit students' engagement and enthusiasm by lacking a true three-dimensional (3D) learning experience. In contrast, Augmented Reality (AR) technology integrates real and virtual elements, enabling users to interact with 3D graphics in a real-world environment [24]. Research has shown that utilizing AR systems in learning leads to prolonged engagement among students, fos-tering enjoyable learning experiences and positively impacting student motivation, understand-ing, and overall impression [25]-[27].

There are two main types of AR for learning: (1) location-aware and (2) vision-based. Loca-tion-aware AR delivers digital content to learners based on their movement through physical spaces, utilizing GPS-enabled smartphones or similar mobile devices. This type of AR can in-corporate text, graphics, audio, video, and 3D models, enhancing the physical environment with narration, navigation, and academic information pertinent to the current location. Conversely, vision-based AR provides digital content to learners when they point the camera on their mobile devices at an object, such as a QR code or a 2D target, as described by Dunleavy in 2014 [3]. AR comprises components as outlined in Table 1.

Table 1. Components of Mobile Augmented Reality.

Component	Description
Computing Platform	Capable of generating and managing virtual objects within a physical setting.
Display Type	1. Shows virtual objects in the context of the real world. 2. Frequently used to convey information obtained according to visual elements.
Registration and Tracking	Arrangement of physical objects with virtual elements for annotation.
Interaction Technology	Enables individuals to select, access, and visualize relevant materials.
Wireless Network	Crucial for involving others while on the go.
Data Storage and Access Technology	Provides information about the current environment to users.

On the other hand, the aforementioned technology unveils a plethora of fundamental charac-teristics that resonate with the evolving educational paradigm. It fosters engaging interaction with diverse learning resources, propels the visualization of information in captivating formats, and empowers the creation of immersive scenarios that amplify conceptual understanding. These transformative capabilities demonstrably have profound repercussions on the learning process, enriching it with deeper engagement, improved knowledge retention, and a strengthened ability to apply theoretical frameworks to real-world situations [28]. In recent times, the use of AR and virtual reality (VR) applications in education is rapidly expanding. AR, in particular, offers sig-nificant potential for illustrating complex concepts and theories in a more dynamic and engaging way. Historically, researchers have developed various learning environments, games, and simu-lations using AR technology, effectively presenting computer-generated graphics to students [29]-[31]. The application areas of AR encompass various domains, including sports, health, gaming, education, culture, marketing, and more [32]. The implementation of AR applications in these fields can be observed in Table 2.

Table 2. Implementation of Augmented Reality.

Field	Researcher
Sports, games and edutainment	[33],[34],[35]
Cultural heritage	[36],[37],[38]
Medical	[39],[40]
Education and training	[41]
Marketing/Advertising	[42]

Kolb's Learning Styles

Kolb's Experiential Learning Theory (ELT) serves as the foundation for Kolb's Learning Style Inventory (LSI), which assesses students' preferences for different stages of the learning cycle. Based on this theory, four distinct learning styles are identified: Converger (AC/AE), Diverger (CE/RO), Assimilator (AC/RO), and Accommodator (CE/AE). Each learning style corresponds to different ways individuals process information and engage with learning. Convergers are adept at applying ideas practically, Divergers are skilled at viewing experiences from multiple perspectives, Assimilators excel in developing theories and working with abstract concepts, and Accommodators thrive through hands-on, active learning. Detailed characteristics and learning objectives for each Kolb learning style can be found in Table 3.

Table 3. Characteristics of Kolb's Learning Styles and Their Learning Objects.

Learning Styles	Characteristics	Objectives
Assimilator	This group utilizes abstract concepts and reflective observation. They excel in using inductive reasoning and are considered "personal learners"	Learning objects may take the form of text-based materials such as audio, video, and oral tutorials.
Accommodator	Students in this group tend to rely on concrete experiences and active experiments. They are highly proficient in hands-on activities.	Learning objects can be structured as text-based materials, including practical exercises, sharing experiences, and tutorials on web pages.
Diverger	Proficient in real-life experiences and reflective observation, Divergers tend to be imaginative and contribute innovative ideas.	Learning objects can be in the form of animations, graphics, and symbols.
Converger	Conceptually abstract and actively experimental, Convergers can apply practical applications of ideas through deductive reasoning. They are also skilled problem solvers.	Learning objects may be structured as text-based materials, such as Microsoft Office and web pages.

METHODS

This research has resulted in a system designed to guide visitors in exploring the UPI campus using mobile devices. In developing this system, a process model was employed to guide the system's construction, and the sequential linear model was utilized for application development. This model is systematic, where each stage of software development is carried out sequentially, starting from analysis, design, coding, and testing.

The use of this development model is based on the characteristics of AR-based learning system development, which requires systematic stages starting from needs analysis, design, development, implementation, to evaluation. Previous studies have shown that AR in education has several advantages, but its development still faces challenges related to usability, learning design, and implementation in real learning contexts [22], [28]. Therefore, a structured development procedure is needed to ensure that the system is not only technically functional but also aligned with learning objectives and user needs. In addition, user acceptance evaluation is also considered important because attitudes towards educational technology can influence the success of technology implementation in learning [14].

Figure 1 explains the multimedia development procedure used in this study. This procedure refers to the ADDIE development model, which consists of five main stages: Analyze, Design, Develop, Implement, and Evaluate. In the Analyze stage, researchers gathered information through literature reviews and field studies to identify learning problems, student needs, and software requirements for developing Augmented Reality-based learning multimedia.

Next, in the Design phase, the researchers developed an AR-based learning multimedia design integrated with the Kolb's Experiential Learning Model. This phase included the creation of flowcharts, storyboards, and AR markers as the basis for media development. The flowcharts were used to illustrate the application's navigation flow, the storyboards were used to design the appearance and content of each page, and the AR markers served as markers to display Augmented Reality objects during the learning process.

In the Development phase, the designs produced in the previous phase were developed into AR-based learning multimedia for mobile devices. This phase included the creation of Bookmarks, the implementation of Kolb's Experiential Learning steps into the media, and initial testing to ensure the media functioned as designed. Furthermore, several technical processes were carried out to support the development of the AR system. First, coordinate point searches were conducted to identify the coordinates of each location or object used as a point for placing the AR model. Second, 3D models were created to develop virtual objects for each Point of Interest (POI) used in the application. Third, location-based Augmented Reality was implemented using Unity3D and Mapbox as a supporting framework to display AR objects based on the user's location. Finally, the AR application was run and tested on an Android device with at least Nougat 7.0 operating system and ARCore support to ensure the AR features worked properly.

After the media was developed, expert validation was conducted to assess the feasibility of the media and learning materials. If the validation results did not meet the feasibility criteria, the media was revised and retested. However, if the media was deemed valid, the product proceeded to the implementation phase.

In the Implement stage, the validated learning multimedia is applied in the learning process. The implementation took place at SMK Negeri 2 Bandung, specifically for the Software Engineering expertise competency. The population in this study were students majoring in Software Engineering at SMK Negeri 2 Bandung, while the sample was 30 grade XI RPL 2 students selected using a purposive sampling technique. In this stage, students participated in learning using Augmented Reality-based multimedia that implemented the Kolb's Experiential Learning Model.

The final stage is Evaluation. This stage involves evaluating the feasibility of developing AR-based learning multimedia. This is then used to evaluate the research results and draw final conclusions regarding the feasibility of the developed media.

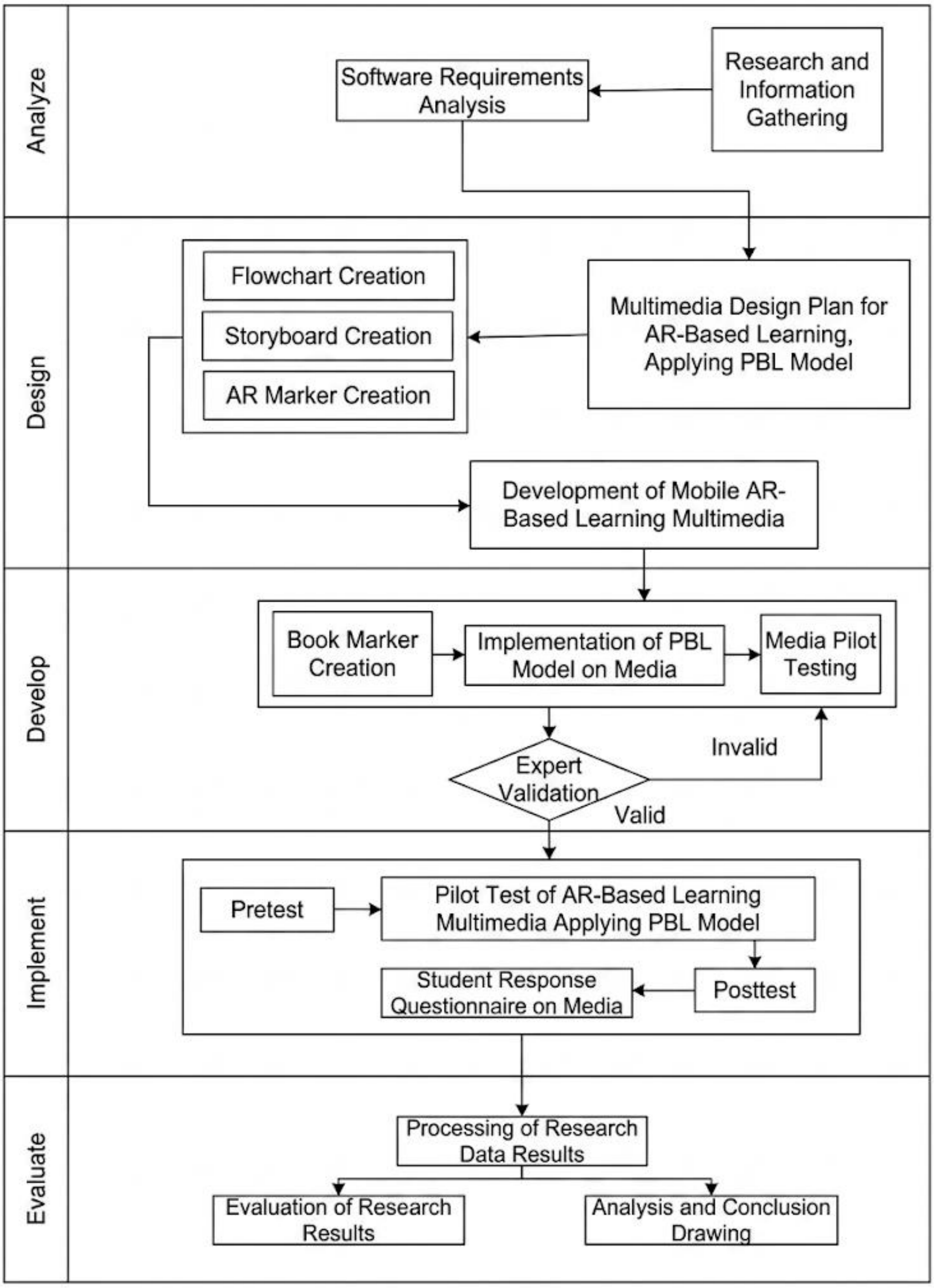

Figure 1. Multimedia Development Procedures.

RESULT AND DISCUSSION

Analyze Stage

The Analyze stage was conducted to identify learning problems, student needs, and system requirements for developing an Augmented Reality-based learning system. The main problem addressed in this study was the limitation of conventional learning, which has increasingly used digital technology but still tends to be static, less interactive, and not fully immersive. Therefore, a learning system that can provide more visual, interactive, and personalized learning experiences is needed. The needs analysis was supported by a preliminary questionnaire distributed to several grade XI Software

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Engineering students. As shown in Figure 2(a), Object-Oriented Programming was the most difficult subject for students. A total of 66.7% of students, or 20 students, stated that they had difficulty understanding Object-Oriented Programming, followed by Static Data Structure with 23.3%, Dynamic Data Structure with 6.7%, and PHP with 3.3%. These findings indicate that Object-Oriented Programming requires a more interactive and visual learning approach to help students understand abstract programming concepts.

The questionnaire also showed that most students preferred collaborative learning. As presented in Figure 2(b), 63.3% of students, or 19 students, preferred group-based learning, while 36.7% preferred individual learning. This finding indicates that the developed learning system needs to support both individual and collaborative learning activities. Therefore, the system was designed to include individual activities such as pre-test and post-test, as well as group activities through Student Worksheets (LKPD). This combination was expected to support students' independent understanding while also encouraging collaboration during the learning process. In terms of learning media, students stated that they had previously used PowerPoint presentations, videos, websites, and e-modules in PDF format. However, these media were still considered insufficient to fully support interactive and immersive learning experiences. This condition strengthened the need to develop AR-based learning media that could present learning materials through 3D visualization, animation, and direct interaction with learning objects.

The preliminary questionnaire also revealed several problems related to students' logical thinking activities. Figure 2(c) shows that 73.3% of students, or 22 students, only occasionally concluded learning materials in class, while 16.7% never did so and only 10% often concluded the materials. In addition, Figure 2(d) shows that 70% of students, or 21 students, only occasionally gave arguments or opinions about the materials delivered by the teacher, while 23.3% never did so and only 6.7% often gave arguments. Furthermore, as shown in Figure 2(e), 53.3% of students, or 16 students, sometimes experienced difficulty solving problems from case studies or questions given by the teacher, while 43.3% often experienced difficulty and only 3.3% never experienced such difficulty.

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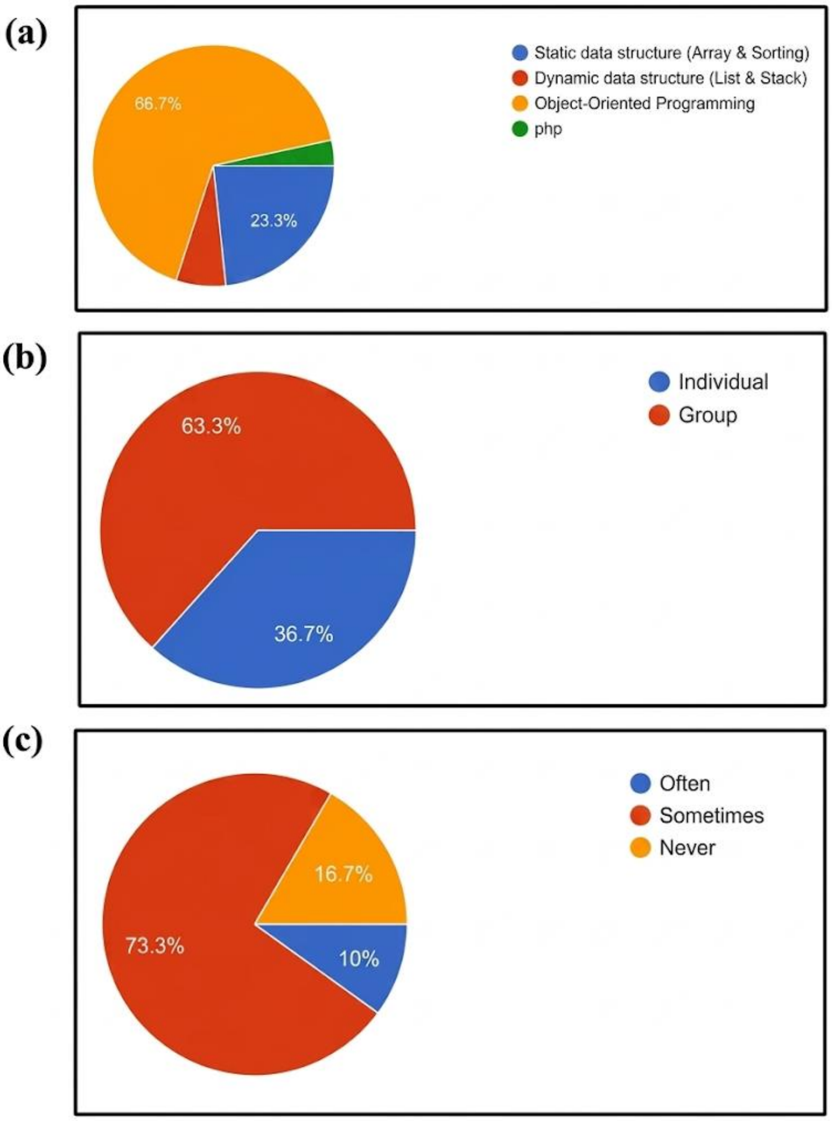

Figure 2. Preliminary needs analysis of grade XI Software Engineering students: (a) percentage of subjects considered difficult by students; (b) students' preference for individual and group learning; (c) students' ability to draw conclusions in learning; (d) students' ability to give arguments in learning; and (e) students' problem-solving ability in learning.

Based on these findings, the developed system was designed not only to present learning materials but also to support students in observing, analyzing, arguing, solving problems, and drawing conclusions. The use of Augmented Reality was considered relevant because AR can combine virtual objects with real environments and provide students with direct visual interaction with learning materials. Previous studies have shown that AR can increase students' motivation, attention, confidence, and comfort in learning [1]–[3]. In addition, AR is also aligned with constructivist learning principles because it allows students to observe, explore, and interact with learning objects in a more contextual environment [4], [5].

In this study, the system was also designed to support learning personalization based on Kolb's Experiential Learning Model. The need for personalization emerged because students have different learning styles, so uniform learning methods may not fully accommodate their learning characteristics. Therefore, the developed system integrates AR visualization with learning activities that are adjusted to students' learning preferences. This is in line with previous research showing that the use of AR in learning can be more effective when it considers students' characteristics and learning styles [8].

Design Stage

Figure 3 illustrates the learning process flow developed in this study, which is based on AR and adapted to Kolb's learning style. The main components in this model consist of: Students, Learning Preference Assessment, Learning according to Learning Style, Materials, Augmented Reality, and Assessment. The process begins with an assessment of students' learning preferences through a valid instrument that identifies Kolb's four learning styles: Diverger, Assimilator, Converger, and Accommodator. The results of this assessment are used to determine the appropriate learning approach for each individual. The material presented is adapted to the characteristics of the learning style and is reinforced through an AR-based interactive display to improve conceptual understanding. This learning stage ends with an evaluation to measure mastery of the material and its impact on student motivation and learning engagement. This model emphasizes personalization of learning and the use of interactive technology as a strategy to increase effectiveness and comfort in the learning process, as well as support the achievement of learning objectives more optimally.

The design of this learning flow emphasizes the role of AR as more than a visualization tool. AR is positioned as part of the learning experience that supports observation, exploration, and interaction with learning objects. This design is relevant to previous studies which reported that AR-based learning can increase engagement and conceptual understanding through interactive visualization [9], [10]. Therefore, the learning flow was designed to connect learning style, learning material, AR interaction, and assessment in one integrated system.

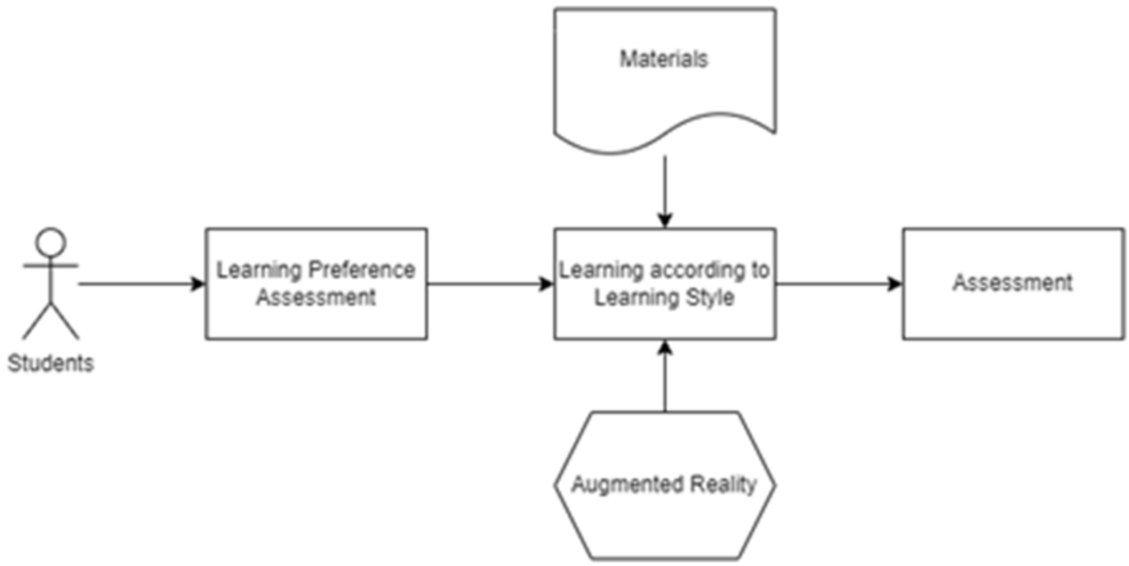

Figure 3. Learning flow model

Figure 4 illustrates the interaction of users, in this case students, with the Augmented Reality-based learning system. Based on Figure 4, students as the main actors have access to several system features, starting from reading tutorials in the form of video guides, as well as reading information relevant to the material or technical use of the application. The core activity in this system is the learning process, which includes displaying learning objectives, accessing teaching materials, and working on LKPD in digital format. One of the superior features of this LKPD is the integration of Augmented Reality technology, which allows students to see animated or 3D objects when the device is directed at a certain marker. The learning process is continued with learning evaluation, which consists of a pretest to measure initial understanding, a quiz as a formative evaluation, and a posttest to assess the final learning outcomes. Through this entire series of interactions, the system is designed to support adaptive and interactive learning, utilizing AR to improve conceptual understanding and an interesting learning experience.

The design of the system also supports active learning because students are not only required to read materials but also to interact with AR objects, complete worksheets, and answer formative evaluation questions. This approach is consistent with the view that visual and interactive representations can strengthen conceptual understanding and memory retention in learning [44].

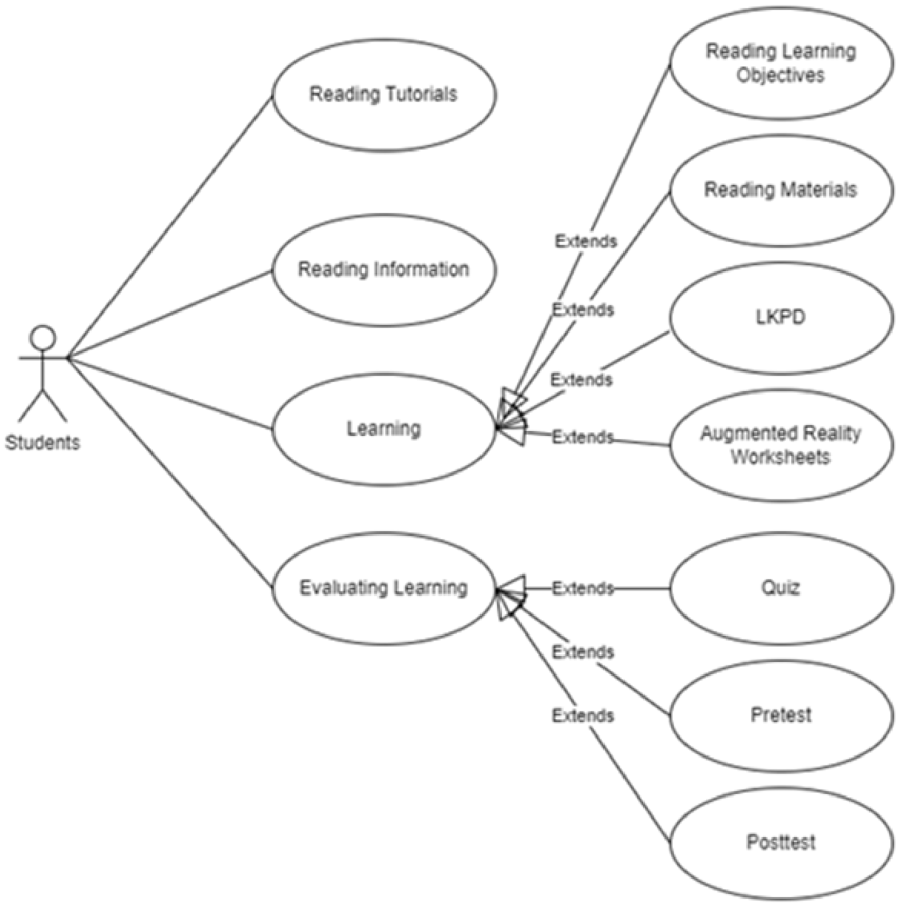

Figure 4. Use case diagram

Develop Stage

In developing an augmented reality campus guide application used to display tour guide models at the Indonesian Education University, several steps that can be taken are:

a. Coordinate Point Search, namely identifying the coordinates of each building at the Indonesian Education University as a point for placing the tour guide model.
b. 3D Model Creation, namely the process of creating a 3D model for each Point of Interest (POI) that will be used.
c. Implementation of Location-Based Augmented Reality, namely implementing location-based augmented reality using Unity3D with Mapbox as an augmented reality framework.
d. Operation of the Augmented Reality Campus Guide Application is used to operate the augmented reality campus guide application created for the Indonesian Education University, an Android device with the Nougat 7.0 operating system and ARCore application support is required.

Figure 5 shows the learning and evaluation interface display on the application. Based on Figure 5, the evaluation process is carried out through several stages, namely pre-test and post-test individually to measure the initial understanding and improvement of participant competence. In addition, there are also activities to work on Student Worksheets (LKPD) which are carried out in groups to develop collaboration skills and a deeper understanding of concepts. With this combination of individual and group evaluations, the application can provide a comprehensive picture of the effectiveness of the learning process and the achievement of participant competence.

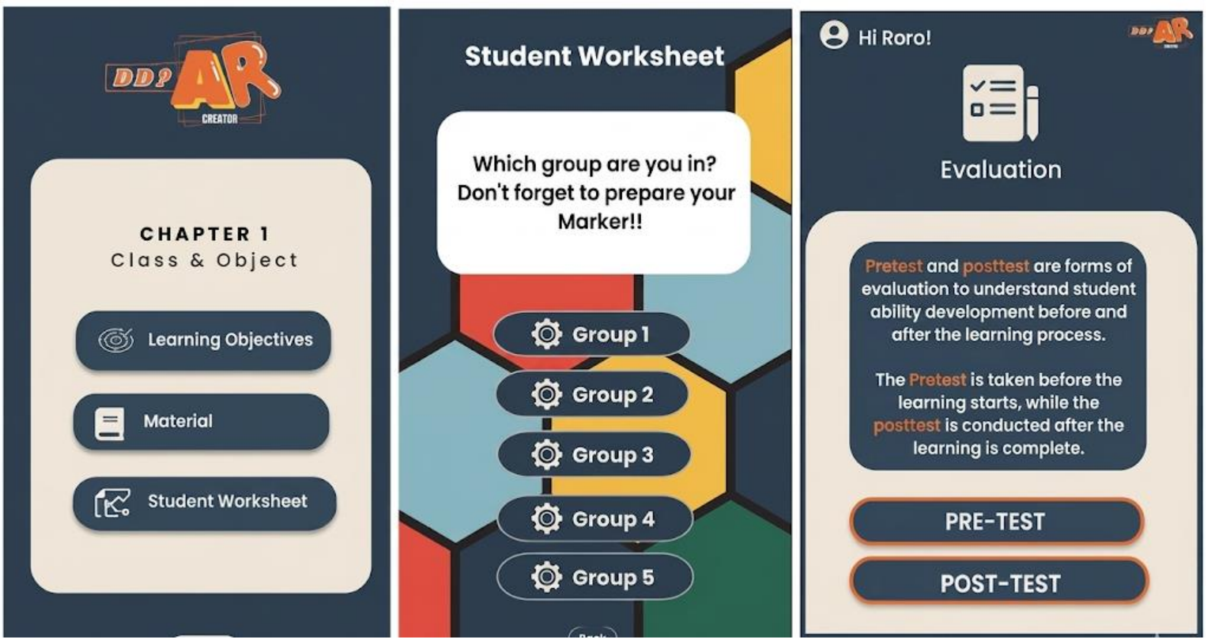

Figure 5. Learning and evaluation interface.

The developed system was tested on 30 11th-grade RPL 2 students at SMK Negeri 2 Bandung. Students used an AR-based learning application via mobile devices to participate in the learning process, complete pre- and post-tests, and provide feedback on the media used. The questionnaire used in this study was structured based on the components of the Technology Acceptance Model (TAM). Questions covered aspects of perceived usefulness, perceived ease of use, attitude toward use, and intention to use. Perceived usefulness was used to determine the extent to which students felt the media could improve understanding, facilitate learning, and support the achievement of learning outcomes. Perceived ease of use was used to assess the ease of procedures, achievement of learning objectives, and ease of use of the media. Meanwhile, attitude toward use and intention to use were used to determine students' attitudes toward using the media and their tendency to use and recommend it.

In addition to the application interface, this study also demonstrated how the Augmented Reality feature works. The AR feature works by pointing the mobile device's camera at a specific marker in the Bookmarker or LKPD Book. When the marker is detected, the system displays a virtual object, animation, or appropriate learning material on the device screen. Students then use these AR objects to observe the material, analyze problems, answer questions, and complete learning activities. With this mechanism, the application functions not only as a medium for presenting information but also as an interactive learning tool that connects 3D visualizations with students' logical thinking activities.

Figure 6 shows the AR visual display when the device's camera is pointed at a specific marker. In this display, virtual objects appear on the device screen according to the scanned marker. This visualization clarifies that the AR system works through the process of marker detection and displays learning content based on 3D objects, animations, or material information. By adding this visualization, the research results not only display the application's homepage but also demonstrate the key interactions between the user, markers, and AR objects in the learning process.

Figure 6. Augmented Reality visualization display when the device is directed at a specific marker or location point.

Implement Stage

The implementation phase involved implementing a validated AR-based learning system in a real classroom context. The implementation took place at SMK Negeri 2 Bandung, a program specializing in Software Engineering. The system was tested with 36 11th-grade RPL 2 students selected using a purposive sampling method. During implementation, students used the AR-based learning application via mobile devices. They accessed learning materials, scanned AR markers, observed AR visualizations, completed worksheets, answered mini-quizzes, and completed pre- and post-tests. The pre-test was used to measure students' initial understanding, while the post-test was used to identify learning improvements after using the application.

In addition to the learning evaluation, students also completed a questionnaire to provide feedback on the application. The questionnaire was structured based on the Technology Acceptance Model (TAM), which consists of four components: perceived usefulness, perceived ease of use, attitude toward use, and intention to use. Perceived usefulness measured the extent to which students felt the application helped improve understanding and supported learning outcomes. Perceived ease of use assessed the ease of operation of the application. Meanwhile, attitudes toward use and intentions to use were used to identify students' attitudes and willingness to continue using the application.

Implementation results indicate that the system can be used in classroom learning activities and can support interactive learning. The use of AR visualizations allows students to interact with virtual objects directly through mobile devices. This supports the notion that AR-based learning environments can increase engagement and provide a more immersive learning experience [10], [13]. Therefore, the implementation results indicate that the developed system is relevant to the learning problems identified at the beginning of the study.

Evaluate Stage

First, the application was evaluated using the black box testing method. This method focuses on testing system functions based on the expected output without examining the internal structure of the program code. Therefore, black box testing was considered appropriate to assess whether each feature in the application worked according to the initial design. The tested components included tutorial video playback, navigation to learning objectives, access to learning materials, AR marker scanning, AR-based worksheets, pre-test and post-test access, and mini quiz interaction. The results of the black box testing are presented in Table 4.

Table 4. Results of Blackbox Testing

No.	Test Item	Scenario	Expected Result	Result
1	Tutorial	Pressing the play video button	Displays a tutorial video for using the app	Pass
2	Learning Objectives	Pressing the back button	Returns to the chapter page	Pass
3	Learning Process	Pressing the chapter button	Navigates to chapter 1 page	Pass
4	Learning Material	Pressing next/prev button for slides	Displays the summary of the chapter material	Pass

No.	Test Item	Scenario	Expected Result	Result
		Directing the camera to the marker	Displays 3D object/animation	Pass
5	AR Worksheets	Directing the camera to the marker	Displays 3D object based on the group	Pass
6	Learning Evaluation	Pressing the pre-test button	Navigates to the pretest assessment form	Pass
		Pressing the post-test button	Navigates to the posttest assessment form	Pass
7	Mini Quiz	Reading the question	Displays the question	Pass
		Pressing the true button	Displays the chosen answer result	Pass
		Pressing the false button	Displays the chosen answer result	Pass

Based on Table 4, all main functions of the system operated properly and met the expected results. No major bugs or technical constraints were found during the testing process. This indicates that the developed AR-based learning system was technically feasible for further implementation in classroom learning. The successful operation of the main features also shows that the system was ready to support learning activities, from accessing materials and AR visualization to completing formative and summative evaluations. This systematic testing process is in line with system validation practices in educational software development as recommended in previous studies [43].

After the functional evaluation, user acceptance was analyzed using a questionnaire based on the Technology Acceptance Model (TAM). The questionnaire consisted of four components: Perceived Usefulness, Perceived Ease of Use, Attitude, and Intention to Use. The questionnaire was administered to students after the learning process to identify their perceptions of the developed AR-based learning system. The TAM measurement results are presented in Table 5.

Table 5. TAM Measurement Results.

No.	Component	Score
1	Perceived Usefulness	78.70
2	Perceived Ease of Use	80.00
3	Attitude	88.17
4	Intention to Use	74.19
	Average	80.26

Based on Table 5, the highest score was obtained in the Attitude component, with a score of 88.17, while the lowest score was obtained in the Intention to Use component, with a score of 74.19. The overall average score was 80.26, indicating that the AR-based learning system was categorized as very good and was positively accepted by students. This result shows that students had a favorable attitude toward the use of the application and perceived it as useful and easy to use in the learning process.

To further examine the relationship among the TAM components, a correlation analysis was conducted. The correlation among TAM components is presented in Figure 7.

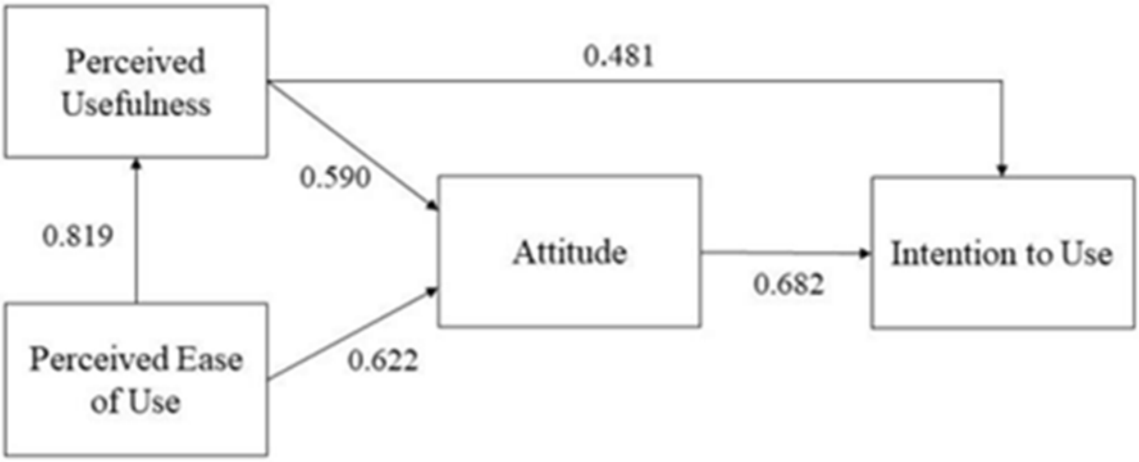

Figure 7. TAM correlation relationship

As shown in Figure 7, the analysis indicates positive relationships among Perceived Usefulness, Perceived Ease of Use, Attitude, and Intention to Use. Perceived Ease of Use had a strong relationship with Perceived Usefulness, with a correlation coefficient of 0.819. This indicates that when students found the application easy to use, they were more likely to perceive it as useful. This finding is consistent with previous research which emphasized that Perceived Ease of Use significantly affects Perceived Usefulness and subsequently influences users' attitudes toward technology adoption [46].

CONCLUSION

This research demonstrates that an Augmented Reality-based learning system developed through the ADDIE phase can provide a solution to the limitations of conventional learning, which tends to be static, less interactive, and less fully immersive. Through the analysis phase, learning needs were identified as the basis for system development. In the design and development phase, the system was designed by integrating AR visualizations, 3D models, and learning flows based on Kolb's Experiential Learning Model to support a more personalized, interactive learning experience that aligns with student learning characteristics.

Test results demonstrated that the application functioned as intended through black box testing and was usable by students in the learning process. Student implementation also demonstrated that the system was easy to use, engaging, and capable of supporting active engagement in learning. Evaluation using the Technology Acceptance Model (TAM) indicated that perceived ease of use and perceived usefulness played a significant role in shaping students' attitudes and intentions to use the application. With an average TAM score of 80.26, the system was deemed feasible and well-received by users.

Thus, this study concludes that the integration of Augmented Reality, Kolb's Experiential Learning Model, and TAM evaluation can support the development of more adaptive, immersive, and student-centered learning systems. The implications of this research indicate that AR has great potential in the development of future learning technologies. Further development can be directed at the integration of artificial intelligence to enhance learning personalization and provide a learning experience that is more responsive to each student's needs.

REFERENCES

[1] Á. Di Serio, M. B. Ibáñez, and C. D. Kloos, "Impact of an augmented reality system on students' motivation for a visual," *Computers and Education*, vol. 68, pp. 586–596, 2013.

[2] Y. S. Chang, "Applying the arcs motivation theory for the assessment of ar digital media design learning effectiveness," *Sustainability*, vol. 13, no. 21, p. 12296, 2021.

[3] M. D. Gómez-Rios, M. Paredes-Velasco, R. D. Hernández-Beleño, and J. A. Fuentes-Pinargote, "Analysis of emotions in the use of augmented reality technologies in education: A systematic review," *Computer Applications in Engineering Education*, vol. 31, no. 1, pp. 216-234, 2023.

[4] M. Dunleavy, "Design principles for augmented reality learning," *TechTrends*, vol. 58, no. 1, pp. 28-34, Dec. 2014.

[5] S. A. Mohamad, R. Zaharudin, Y. Kamin, and N. H. M. N. Mustapha, "Integrating augmented reality with cognitive constructivist theory: A systematic review of enhancing learning in education," *Journal of Contemporary Social Science and Education Studies (JOCSSES)*, vol. 4, no. 3, pp. 124-132, 2024.

[6] J. Welker and L. Berardino, "Blended learning: Understanding the middle ground between traditional classroom and fully online instruction," *Journal of Educational Technology Systems*, vol. 34, no. 1, pp. 33-55, 2005.

[7] P. R. Humanante-Ramos, F. J. García-Peñalvo, and M. Á. Conde-González, "Personal learning environments and online classrooms: An experience with university students," *IEEE Revista Iberoamericana de Tecnologías del Aprendizaje*, vol. 10, no. 1, pp. 26-32, 2015.

[8] P. Liu, Z. Yang, J. Huang, and T. K. Wang, "The effect of augmented reality applied to learning process with different learning styles in structural engineering education," *Engineering, Construction and Architectural Management*, 2024.

[9] N. A. M. Mokmin, S. Hanjun, C. Jing, and S. Qi, "Impact of an AR-based learning approach on the learning achievement, motivation, and cognitive load of students on a design course," *Journal of Computers in Education*, vol. 11, no. 2, pp. 557-574, 2024.

[10] W. B. Latif, I. M. Y. Yasin, M. A. Rahaman, M. S. Forid, M. N. Islam, and M. Z. Hossain, "Impact of augmented reality (AR) and virtual reality (VR) on interactive learning systems," *Pacific Journal of Advanced Engineering Innovations*, vol. 1, no. 1, pp. 23-32, 2024.

[11] C. Y. Hung, Y. T. Lin, S. J. Yu, and J. C. Y. Sun, "Effects of AR-and VR-based wearables in teaching English: The application of an ARCS model-based learning design to improve elementary school students' learning motivation and performance," *Journal of Computer Assisted Learning*, vol. 39, no. 5, pp. 1510-1527, 2023.

[12] Y. Hwang and P. Huang, "Augmented Reality-Assisted Learning: Enhancing Vocabulary Acquisition and Motivation in Elementary English Education," SSRN, 2025. [Online]. Available: https://ssrn.com/abstract=5134189

[13] W. O. Riniati, D. Jiao, and S. N. Rahmi, "Application of augmented reality-based educational technology to increase student engagement in elementary schools," *International Journal of Educatio Elementaria and Psychologia*, vol. 1, no. 6, pp. 305-318, 2024.

[14] N. Saif, S. U. Khan, I. Shaheen, F. A. ALotaibi, M. M. Alnfiai, and M. Arif, "Chat-GPT; validating Technology Acceptance Model (TAM) in education sector via ubiquitous learning mechanism," *Computers in Human Behavior*, vol. 154, Article 108097, 2024.

[15] O. A. Alismaiel, J. Cifuentes-Faura, and W. M. Al-Rahmi, "Social media technologies used for education: An empirical study on TAM model during the COVID-19 pandemic," *Frontiers in Education*, vol. 7, Article 882831, 2022.

[16] X. Li, W. H. Tan, Y. Bin, P. Yang, Q. Yang, and T. Xu, "Analysing factors influencing undergraduates' adoption of intelligent physical education systems using an expanded TAM," *Education and Information Technologies*, vol. 30, no. 5, pp. 5755–5785, 2025.

[17] H. Afifah, T. Ibrahim, and O. Arifudin, "Implementasi Technology Acceptance Model (TAM) pada penerimaan aplikasi sistem manajemen pendidikan di lingkungan madrasah," *Jurnal Tahsinia*, vol. 5, no. 9, pp. 1353–1369, 2024.

[18] V. Bong and M. D. Firmansyah, "Analisa Duolingo terhadap prestasi Bahasa Inggris siswa SMP Batam dengan metode TAM," *Jurnal Informasi dan Teknologi*, vol. 5, no. 3, pp. 122–130, 2023.

[19] P. Liu, N. D. Georganas, and P. Boulanger, "Designing real-time vision based augmented reality environments for 3D collaborative applications," in *Proc. IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2002.

[20] N. I. Adhani and D. R. A. Rambli, "A survey of mobile augmented reality applications," in *1st International Conference on Future Trends in Computing and Communication Technologies*, 2012, pp. 89-96.

[21] S. Mystakidis, A. Christopoulos, and N. Pellas, "A systematic mapping review of augmented reality applications to support STEM learning in higher education," *Education and Information Technologies*, vol. 27, no. 2, pp. 1883-1927, 2022.

[22] M. Akçayır and G. Akçayır, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," *Educational Research Review*, vol. 20, pp. 1-11, 2017.

[23] M. Antonioli, C. Blake, and K. Sparks, "Augmented reality applications in education," *The Journal of Technology Studies*, pp. 96-107, 2014.

[24] M. Akçayır, G. Akçayır, H. M. Pektaş, and M. A. Ocak, "Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories," *Computers in Human Behavior*, vol. 57, pp. 334-342, 2016.

[25] J. M. Andujar, A. Mejías, and M. A. Márquez, "Augmented reality for the improvement of remote laboratories: an augmented remote laboratory," *IEEE Transactions on Education*, vol. 54, no. 3, pp. 492-500, 2010.

[26] M. Dunleavy, C. Dede, and R. Mitchell, "Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning," *Journal of Science Education and Technology*, vol. 18, no. 1, pp. 7-22, 2009.

[27] F. Reyes-Aviles and C. Aviles-Cruz, "Handheld augmented reality system for resistive electric circuits understanding for undergraduate students," *Computer Applications in Engineering Education*, vol. 26, no. 3, pp. 602-616, 2018.

[28] M. Z. Iqbal, E. Mangina, and G. C. Abraham, "Current challenges and future research directions in augmented reality for education," *Multimodal Technologies and Interaction*, vol. 6, no. 9, p. 75, 2022.

[29] K.-H. Cheng and C.-C. Tsai, "Affordances of augmented reality in science learning: Suggestions for future research," *Journal of Science Education and Technology*, vol. 22, pp. 449-462, 2013.

[30] M.-B. Ibáñez, Á. Di-Serio, D. Villarán-Molina, and C. Delgado-Kloos, "Support for augmented reality simulation systems: The effects of scaffolding on learning outcomes and behavior patterns," *IEEE Transactions on Learning Technologies*, vol. 9, no. 1, pp. 46-56, 2015.

[31] J. Martín-Gutiérrez, P. Fabiani, W. Benesova, and M. D. Meneses, "Augmented reality to promote collaborative and autonomous learning in higher education," *Computers in Human Behavior*, vol. 51, pp. 752-761, 2015.

[32] Y. Lee and J. Choi, "Tideland animal AR: Superimposing 3D animal models to user defined targets for augmented reality game," *International Journal of Multimedia and Ubiquitous Engineering*, vol. 9, no. 4, pp. 343-348, 2014.

[33] N. Omarov, B. Omarov, Z. Azhibekova, and B. Omarov, "Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation," *Retos: Nuevas Tendencias en Educación Física, Deporte y Recreación*, no. 60, pp. 269-278, 2024.

[34] P. Soltani and A. H. Morice, "Augmented reality tools for sports education and training," *Computers & Education*, vol. 155, p. 103923, 2020.

[35] O. Y. B. Keat, N. Wahid, N. Murli, and R. A. Hamid, "Augmented reality to induce enjoyment in edutainment mobile game," *JOIV: International Journal on Informatics Visualization*, vol. 2, no. 3-2, pp. 188-193, 2018.

[36] Angelopoulou, D. Economou, V. Bouki, A. Psarrou, L. Jin, C. Pritchard, dan F. Kolyda, "Mobile augmented reality for cultural heritage," dalam *Mobile Wireless Middleware, Operating Systems, and Applications: 4th International ICST Conference, Mobilware 2011, London, UK, June 22-24, 2011, Revised Selected Papers 4*, Springer Berlin Heidelberg, 2012, pp. 15-22.

[37] Y. Li, E. Ch'ng, S. Cai, dan S. See, "Multiuser interaction with hybrid VR and AR for cultural heritage objects," dalam *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)*, 2018, pp. 1-8.

[38] G. Bozzelli, A. Raia, S. Ricciardi, M. De Nino, N. Barile, M. Perrella, ... dan A. Palombini, "An integrated VR/AR framework for user-centric interactive experience of cultural heritage: The ArkaeVision project," *Digital Applications in Archaeology and Cultural Heritage*, vol. 15, p. e00124, 2019.

[39] S. L. Tang, C. K. Kwoh, M. Y. Teo, N. W. Sing, dan K. V. Ling, "Augmented reality systems for medical applications," *IEEE Engineering in Medicine and Biology Magazine*, vol. 17, no. 3, pp. 49-58, 1998.

[40] J. Sutherland, J. Belec, A. Sheikh, L. Chepelev, W. Althobaity, B. J. Chow, ... dan D. J. La Russa, "Applying modern virtual and augmented reality technologies to medical images and models," *Journal of Digital Imaging*, vol. 32, pp. 38-53, 2019.

[41] K. Lee, "Augmented reality in education and training," *TechTrends*, vol. 56, pp. 13-21, 2012.

[42] M. Sripathi dan T. Bhuvaneswari, "Role of augmented reality (AR) in marketing," *Emerging Trends in Business, Commerce & Management*, vol. 1, 2022.

[43] D. Nurdiana, D. A. Aprijani, F. Amastini, M. R. Maulana, dan M. R. P. A. Utama, "Pengembangan Sistem Informasi Pengelolaan Pembimbing Lapangan Praktik Kerja Lapangan (PKL) Prodi Sistem Informasi Universitas Terbuka," *Decode: Jurnal Pendidikan Teknologi Informasi*, vol. 4, no. 2, pp. 418-436, 2024.

[44] M. A. Rau, "Conditions for the effectiveness of multiple visual representations in enhancing STEM learning," *Educational Psychology Review*, vol. 29, pp. 717-761, 2017.

[45] J. Zajda dan J. Zajda, "Constructivist learning theory and creating effective learning environments," dalam *Globalisation and education reforms: Creating effective learning environments*, pp. 35-50, 2021.

[46] D. I. Prastiawan, S. Aisjah, dan R. Rofiaty, "The effect of perceived usefulness, perceived ease of use, and social influence on the use of mobile banking through the mediation of attitude toward use," *APMBA (Asia Pacific Management and Business Application)*, vol. 9, no. 3, pp. 243-260, 2021.
[47] Kemp, E. Palmer, dan P. Strelan, "A taxonomy of factors affecting attitudes towards educational technologies for use with technology acceptance models," *British Journal of Educational Technology*, vol. 50, no. 5, pp. 2394-2413, 2019.