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RESEARCH ARTICLE Open Access

Development of a Mixed Reality Based Learning Application for Microcontroller Education Using the Luther Sutopo Multimedia Development Method

Antoni Pribadi [1*], Ratu Natalia Marjani Ufayrah [2], Andri Nofiar. Am [3], Nurkholis [4], M. Alkadri Perdana [5]

[1*,2] Department of Informatics Engineering, Politeknik Kampar, Bengkalis Regency, Riau Province, Indonesia.
[3] Department of Digital Business, Politeknik Negeri Bengkalis, Bengkalis Regency, Riau Province, Indonesia.
[4] Department of Logistics Engineering Technology, Politeknik Kampar, Bengkalis Regency, Riau Province, Indonesia.
[5] Department of International Business Administration, Politeknik Negeri Bengkalis, Bengkalis Regency, Riau Province, Indonesia.

**Corresponding author*: antonipribadi.polkam@gmail.com.

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Abstract: The rapid advancement of immersive technologies has created new opportunities to improve learning effectiveness, particularly in technical education such as microcontroller systems. Conventional teaching methods still rely heavily on static visualizations and theoretical explanations, which limit students' ability to understand complex hardware interactions. A mixed reality (MR)-based learning application was developed to improve students' conceptual understanding of microcontroller components and their functions in an interactive and immersive environment. The development process followed the Luther–Sutopo multimedia development method, consisting of six stages: concept, design, material collecting, assembly, testing, and distribution. The application was built using Unity and Blender and deployed on the Oculus Meta Quest 2 platform. Usability testing involved 10 vocational students with prior knowledge of microcontrollers. The application achieved an average usability score of 4.54 out of 5 (90.8%), placing it within the "very feasible" category. Beyond feasibility metrics, the system appeared to strengthen students' spatial understanding, engagement, and interaction with microcontroller components. These findings suggest that pairing mixed reality with a structured multimedia development model can meaningfully improve the effectiveness of technical education.

Keywords: Mixed Reality; Microcontroller Learning; Multimedia Learning Media; Luther–Sutopo Method; Immersive Learning Technology.

1. Introduction

The rapid advancement of digital technology has significantly transformed various sectors, including education. Educational institutions have increasingly integrated digital tools into teaching and learning processes to improve the effectiveness of knowledge delivery and sustain student engagement. Technology-based learning environments allow educational content to be presented in interactive, visual, and dynamic forms, enabling students to better understand complex and abstract concepts. The integration of digital technologies as learning media also supports experiential learning, where students can actively interact with learning materials rather than passively receiving information. Sulistiani *et al.* (2023) noted that immersive technologies in education carry the potential to create more engaging learning experiences and improve students' conceptual understanding, particularly in technical and practical subjects.

In engineering and computer science education, the demand for effective visualization tools is especially pressing. Courses related to embedded systems and microcontroller programming require students to understand both theoretical concepts and practical system operations. Microcontrollers serve as essential components in modern electronic devices, ranging from automation systems to Internet of Things (IoT) applications. Yang *et al.* (2022) argued that microcontroller education plays a decisive role in developing the practical and technical skills required in contemporary technological industries. Teaching these concepts, however, remains genuinely difficult in many educational settings. Traditional teaching methods such as lectures, textbooks, and static diagrams often fail to convey the dynamic interactions between hardware components and software instructions. Ansori *et al.* (2021) reported that theoretical approaches alone are insufficient for microcontroller instruction because students require practical visualization to fully understand system architecture and operational mechanisms. That gap — between what static media can show and what students actually need to see — is the central problem this study addresses.

To address these limitations, educators have begun adopting immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) in educational environments. These technologies enable learners to interact with digital objects in three-dimensional environments, thereby improving spatial understanding and learning engagement. Wijayanti *et al.* (2024) found that AR and VR significantly improve student engagement and comprehension by providing interactive and contextual learning experiences. The development of immersive technologies has further led to the emergence of Mixed Reality (MR), which combines elements of augmented and virtual reality by integrating virtual objects directly into the real-world environment. Nadhia *et al.* (2023) stated that mixed reality provides interactive learning environments where digital objects can be manipulated within real-world contexts, strengthening learner understanding and engagement. Zen and Syarif (2022) similarly noted that mixed reality technology can support practical learning by allowing students to explore virtual objects in real time, thereby deepening experiential learning processes.

Several prior studies have demonstrated the effectiveness of mixed reality technology across educational domains. Abidin *et al.* (2021) applied mixed reality to support the revitalization of folklore learning in elementary education. Lopez *et al.* (2021) developed an MR-based training platform for occupational safety education, allowing learners to experience simulated workplace environments. Barrile *et al.* (2022) used mixed reality to visualize archaeological artifacts in museum settings through interactive three-dimensional models. Piankarnka *et al.* (2023) proposed an MR learning model for practical skills in digital character design, reporting measurable gains in both student motivation and performance. Despite this growing body of work, the application of mixed reality in microcontroller learning remains comparatively thin. Rahman *et al.* (2022) developed an AR application for introducing Arduino components using marker-based tracking techniques, and Ronaldo and Wijaya (2023) designed an AR-based learning tool to support microcontroller introduction in computer system courses. Although both systems provide interactive visualization of electronic components, they remain limited in terms of immersion and spatial interaction when compared to mixed reality technologies. Users can only view virtual objects through screens without direct spatial engagement — whereas mixed reality enables real-time interaction between users and virtual objects within the physical environment itself.

Multimedia learning applications are also commonly developed using structured design models. Christina *et al.* (2023) explained that the Luther–Sutopo multimedia development model provides systematic stages — concept, design, material collection, assembly, testing, and distribution — enabling the development of effective and well-structured multimedia learning systems. A clear gap persists, however, in the integration of mixed reality technology with this kind of systematic multimedia development framework for microcontroller education. Existing studies either focus on augmented reality or rely on conventional instructional design models without exploring what MR environments, combined with the Luther–Sutopo method, might genuinely offer. Accordingly, this study: (1) developed a mixed reality-based learning application for microcontroller education using the Luther–Sutopo multimedia development method; (2) evaluated the usability and effectiveness of the developed system; and (3) analyzed the feasibility of MR as an immersive learning medium for vocational students.

2. Related Work

2.1 Mixed Reality in Educational Environments

The development of immersive technologies has opened new opportunities for improving the quality of digital learning environments. Mixed Reality (MR) combines elements of Augmented Reality (AR) and Virtual Reality (VR) to create interactive settings where users engage simultaneously with virtual and real-world objects — a level of integration that neither AR nor VR achieves independently. This technology enables more immersive learning experiences that support visualization and interaction in educational contexts. Nadhia *et al.* (2023) explained that mixed reality allows digital objects to be placed directly into real-world environments, enabling learners to interact with educational content in a more immersive and contextual way. Zen and Syarif (2022) similarly noted that MR environments can support practical learning activities by enabling students to explore virtual objects and simulate real-world scenarios in real time. Prior studies confirm MR's educational value across diverse contexts. Abidin *et al.* (2021) applied mixed reality to support folklore learning in elementary schools through interactive digital storytelling. Lopez *et al.* (2021) developed an MR-based training platform for occupational safety education, where learners could safely simulate workplace environments. In cultural heritage education, Barrile *et al.* (2022) used mixed reality to visualize archaeological artifacts in museums through interactive three-dimensional models. Piankarnka *et al.* (2023) proposed an MR learning model for practical skills in digital character design for animation, reporting that immersive visualization measurably improved students' learning motivation and performance.

2.2 Immersive Learning Technologies in Education

Beyond mixed reality, AR and VR have been widely adopted as learning media in educational environments. These technologies allow students to interact with three-dimensional digital objects, making learning processes more interactive and engaging. Wijayanti *et al.* (2024) reported that AR and VR implementations in education significantly increase student engagement and improve conceptual understanding across multiple subjects. Sulistiani *et al.* (2023) similarly noted that immersive learning environments offer productive approaches for delivering educational content, particularly in technical and practical disciplines where visualization is not optional — it is necessary. In microcontroller education specifically, several studies have attempted to integrate immersive technologies into learning processes. Rahman *et al.* (2022) developed an AR-based application to introduce Arduino components using marker-based tracking techniques, enabling students to visualize electronic components through mobile devices and thereby improving their understanding of hardware structures. Ronaldo and Wijaya (2023) designed an AR-based learning system to support microcontroller introduction in computer system courses, finding that interactive visualization of microcontroller components helps students understand the relationship between hardware components and system functionality more effectively. What both studies share, however, is a reliance on screen-mediated AR — which limits the depth of spatial interaction available to learners. The implementation of mixed reality in microcontroller learning, by comparison, remains relatively limited.

2.3 Multimedia Development Methods in Learning Systems

The development of digital learning media generally follows systematic instructional design models to ensure that applications are built in a structured and effective manner. Several models have been widely used in educational multimedia development, including ADDIE, Agile Scrum, and the Luther–Sutopo multimedia development model. Christina *et al.* (2023) explained that the Luther–Sutopo model consists of six systematic stages — concept development, design, material collection, assembly, testing, and distribution — providing a clear framework for developing interactive multimedia learning applications. Manumpil (2024) developed multimedia-based learning media for multimedia courses and found that interactive multimedia applications can improve learning effectiveness and student engagement, confirming that structured development models help ensure educational applications are designed systematically and aligned with learning objectives. Despite the availability of various multimedia development approaches, most immersive learning applications are still developed using conventional instructional design models such as ADDIE. The integration of mixed reality technology with the Luther–Sutopo multimedia development model has received little attention in the literature. That gap is precisely what this study addresses — investigating how this development model can be applied to design more effective immersive learning applications for technical subjects such as microcontroller education.

3. Methodology

3.1 Research Type

This study is classified as development research, aimed at producing mixed reality-based learning media for introducing microcontroller devices. The development was intended to improve students' understanding of microcontroller components and working principles through interactive and immersive three-dimensional visualization. The development process followed the Luther–Sutopo multimedia development method, which consists of six main stages: concept, design, material collecting, assembly, testing, and distribution. This method provides a systematic framework for multimedia system development and is well suited to immersive learning applications. The overall stages are illustrated in Figure 1. All stages were conducted sequentially to ensure that the resulting learning media met instructional objectives and could be effectively used by target users.

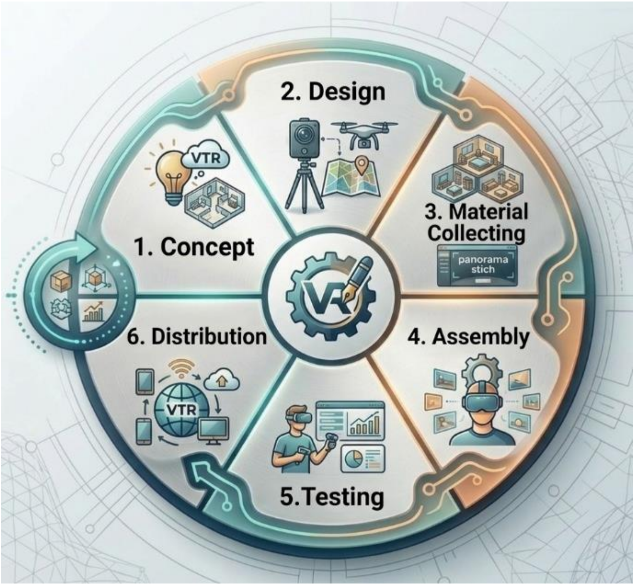

Figure 1. Luther Sutopo Multimedia Development Method

3.2 Research Subjects

The research subjects were users who participated in the evaluation of the developed mixed reality learning application. A total of 10 students from the Diploma (D3) Informatics Engineering Study Program at Politeknik Kampar, Riau, served as respondents. The sample size was determined based on usability testing principles proposed by Nielsen, which state that 5–10 participants are sufficient to identify most usability issues in interactive systems — a widely cited threshold that, while modest, is appropriate for this stage of evaluation. The respondents were selected because of their relevant background knowledge in microcontroller systems. During testing, participants interacted with the mixed reality application and provided feedback on usability, clarity of learning content, and system interactivity.

3.3 Research Tools

The research tools used in this study consist of both hardware and software components. The hardware includes an Asus TUF Gaming A15 laptop equipped with an Intel Core i5 processor as the primary development device, and an Oculus Meta Quest 2 headset powered by the Qualcomm Snapdragon XR2 processor as the mixed reality interaction device. On the software side, Unity Engine version 6000.0.29f1 served as the primary platform for developing the mixed reality application — used to integrate three-dimensional objects, user interfaces, and interaction systems — while Blender version 4.1.1 was used for creating and modifying three-dimensional models of microcontroller devices displayed in the application.

3.4 Research Stages

The development of the mixed reality learning media followed the six stages of the Luther–Sutopo development method. The overall development stages and workflow of the system are illustrated in Figure 2.

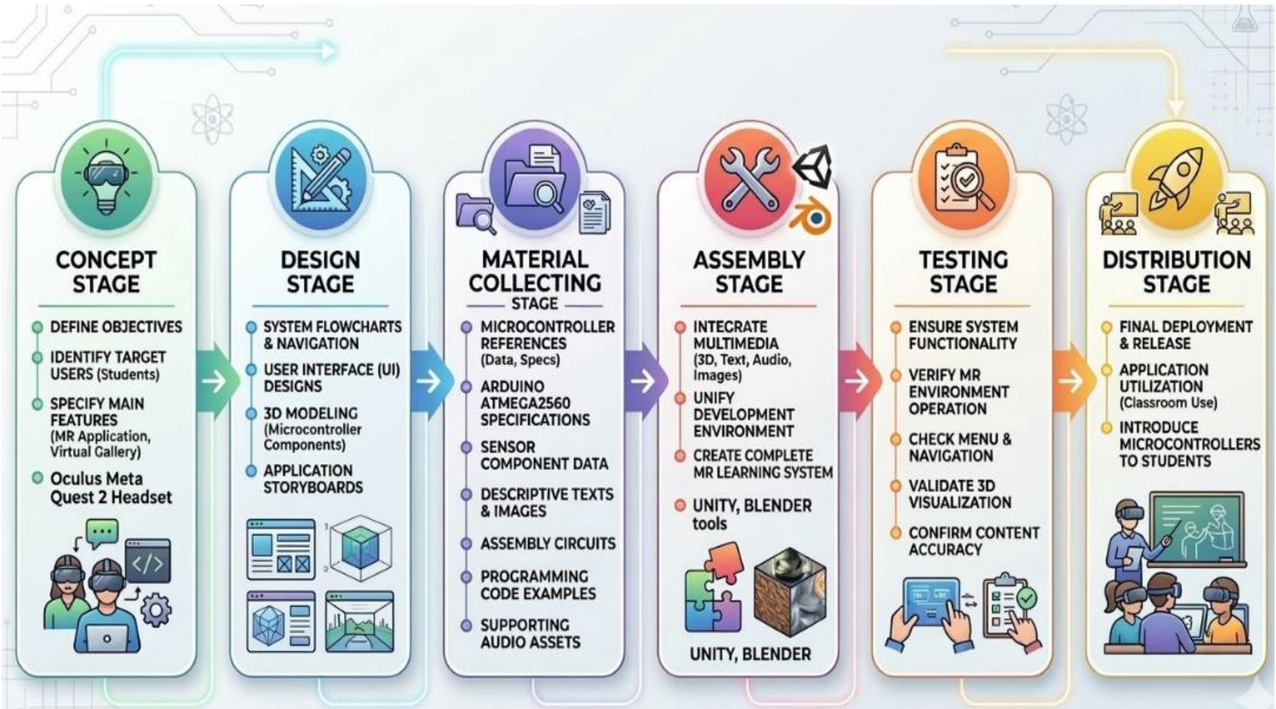

Figure 2. Flowchart of the Mixed Reality Learning Media Development Process

1) Concept Stage
   This stage defined the system's objectives, target users, and main features. The application was designed as mixed reality learning media for introducing microcontroller devices within a virtual gallery learning environment, accessible through the Oculus Meta Quest 2 headset.
2) Design Stage
   The design stage involved developing system flowcharts, navigation structures, and user interface designs. Three-dimensional models of microcontroller components were designed, and application storyboards were created to illustrate user interaction with the system.
3) Material Collecting Stage
   At this stage, all materials required for development were gathered: microcontroller device references, Arduino ATmega2560 specifications, sensor component data, descriptive texts, circuit assembly images, simple programming code examples, and supporting audio assets.
4) Assembly Stage
   The assembly stage integrated all multimedia elements collected in the previous stage. Three-dimensional objects, text, images, and audio were combined within the Unity development environment using Blender and Unity tools to produce a complete mixed reality learning system.
5) Testing Stage
   The testing stage verified that the developed application functions correctly within the mixed reality environment. The testing process covered menu functionality, navigation systems, three-dimensional object visualization, and the accuracy of presented learning content.
6) Distribution Stage
   At the final stage, the mixed reality application was deployed and made available as learning media for introducing microcontroller devices to students.

3.5 Data Collection and Analysis Techniques

Data collection was conducted through observation, documentation, and questionnaires. Observation was carried out to identify learning needs and evaluate the usage of the developed learning media. Documentation involved capturing images of microcontroller devices available in the Informatics Engineering laboratory at Politeknik Kampar, which served as references for three-dimensional model creation. Questionnaires were distributed to respondents to evaluate the usability and effectiveness of the application, covering aspects such as ease of use, clarity of learning materials, and system interactivity. The questionnaire consisted of 15 items grouped into five evaluation aspects: visual quality, content clarity, usability, interactivity, and user satisfaction. A 5-point Likert scale (1 = very poor to 5 = very good) was used. The instrument was reviewed by two experts in multimedia learning to ensure content validity. The collected data were analyzed using descriptive statistical methods, including mean score calculation, percentage distribution, and feasibility classification. Feasibility was calculated using the following formula:

$$Feasibility(\%) = \frac{Obtained\ Score}{Maximum\ Score} \times 100\%$$

The feasibility criteria were defined as follows: 81–100% (very feasible), 61–80% (feasible), 41–60% (moderate), 21–40% (less feasible), and 0–20% (not feasible). The analysis results were used to determine the feasibility level of the mixed reality-based learning media developed in this study.

4. Result and Discussion

4.1 Results

The implementation stage successfully produced a mixed reality learning application that enables users to interact with three-dimensional microcontroller components within an immersive virtual environment. The application operates using the Oculus Meta Quest 2 headset, which supports spatial interaction and visualization of digital objects within real-world space. The developed system consists of several main functional modules, including the main menu interface, microcontroller learning gallery, control menu, about menu, and exit menu. Each module was designed to facilitate user interaction and ensure intuitive navigation within the mixed reality learning environment. The main interface displays of the system are summarized in Table 1.

Table 1. Interface Display of the Mixed Reality Learning Application

Figure	Interface Menu	Description
	Main Menu	Main interface used to access all features of the application
	Microcontroller Gallery	Displays three-dimensional microcontroller components in the virtual environment
	Control Menu	Provides instructions for operating the system
	About Menu	Displays information about the application

	Exit Menu	Allows users to terminate the application safely

4.1.1 Implementation Results

To verify that the developed application operates correctly and reliably, a comprehensive testing process was conducted. The testing phase aimed to confirm that each system component functions according to design specifications and provides a stable user experience. The testing procedures consisted of navigation testing, asset testing, and trigger event testing. Navigation testing determined whether users could explore the mixed reality learning environment and adjust their viewing direction without system errors or orientation issues. As shown in Table 2, all thirteen tested navigation directions — ranging from 30° to 360° — functioned successfully. The virtual environment responded appropriately to user head movement, and visualization remained stable without noticeable lag or orientation errors, confirming that the navigation system operates as intended.

Table 2. Navigation Direction Testing Results

Viewing Direction	System Response
30°	Success
45°	Success
90°	Success
120°	Success
135°	Success
150°	Success
180°	Success
210°	Success
240°	Success
300°	Success
315°	Success
330°	Success
360°	Success

Asset testing verified that all multimedia elements were displayed correctly, including three-dimensional models, textures, and spatial positioning within the virtual environment. These results confirm that the integration between Blender and Unity was successfully implemented. Trigger event testing then evaluated the interaction mechanism between users and virtual objects. As presented in Table 3, all sixteen component objects responded correctly when selected, and the corresponding information was displayed without delay — confirming that the interaction mechanism functions effectively within the mixed reality environment.

Table 3. Trigger Event Testing Results

Object Component	Information Display	Result
Arduino ATmega2560	Component information displayed	Success
LED	Component information displayed	Success
USB Type B Cable	Component information displayed	Success
Jumper Cable	Component information displayed	Success
Breadboard	Component information displayed	Success
Resistor	Component information displayed	Success
Pushbutton	Component information displayed	Success
Potentiometer	Component information displayed	Success
LCD Module	Component information displayed	Success
Load Cell	Component information displayed	Success
PIR Sensor	Component information displayed	Success
DHT11 Sensor	Component information displayed	Success
Soil Moisture Sensor	Component information displayed	Success
Ultrasonic Sensor	Component information displayed	Success
Servo Motor	Component information displayed	Success
MQ-2 Gas Sensor	Component information displayed	Success

4.1.2 Performance Evaluation

Performance evaluation was conducted through usability testing involving ten students. Respondents interacted with the application and completed a questionnaire assessing usability, effectiveness, and user satisfaction across five evaluation aspects, as presented in Table 4.

Table 4. User Response Evaluation

No	Evaluation Aspect	Score 1	Score 2	Score 3	Score 4	Score 5
1	Accuracy of 3D models	0	0	10%	30%	60%
2	Clarity of learning materials	0	0	10%	20%	70%
3	Visual appearance	0	0	10%	20%	70%
4	Ability to recognize components	0	0	10%	20%	70%
5	Ease of system usage	0	0	10%	40%	50%

Responses were concentrated in the score 4 and score 5 categories, suggesting that users found the system visually appealing, reasonably easy to use, and supportive of learning. The visualization of questionnaire results presented in Figure 3 and Figure 4 shows that the majority of responses fell in score 5 (64%) and score 4 (26%), reflecting positive user perceptions of the system overall. Mean scores per evaluation aspect were also calculated to improve data transparency. The highest score was obtained for clarity of learning materials (mean = 4.6), followed by visual appearance (mean = 4.5). The lowest score was recorded for ease of system usage (mean = 4.3) — a modest gap that nonetheless suggests user interface design warrants further attention in subsequent iterations.

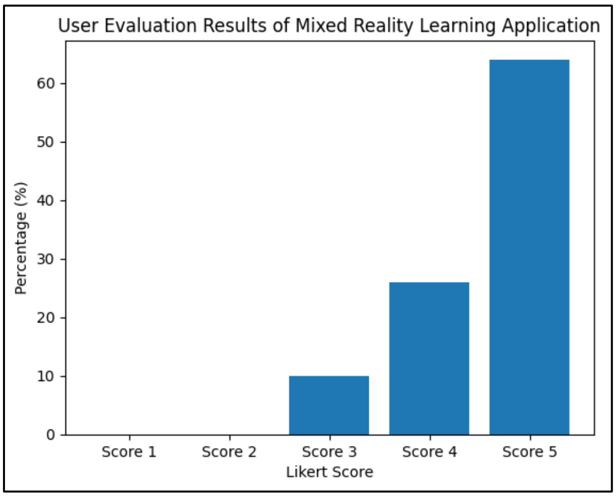

Figure 3. Bar Chart

4.1.3 Evaluation Metrics

The questionnaire results were analyzed using a Likert scale with five levels ranging from 1 (very poor) to 5 (very good). The average score obtained was 4.54 out of a maximum of 5. The success rate was calculated as follows:

$$Success\ Rate = \frac{4.54}{5} \times 100\% = 90.8\%$$

The developed mixed reality learning application falls within the "very feasible" category, meeting user expectations in terms of usability, interactivity, and learning effectiveness.

4.2 Discussion

The results of this study indicate that mixed reality technology can meaningfully improve the effectiveness of learning media for technical subjects such as microcontroller education. The developed system provides an immersive learning environment where students interact directly with three-dimensional representations of electronic components — something that a printed circuit diagram simply cannot replicate. This aligns with Dede (2009), who argued that immersive interfaces foster deeper engagement by allowing learners to experience content rather than merely observe it, and with Slater and Wilbur (1997), whose foundational framework established that the degree of immersion in a virtual environment directly influences user presence and interaction quality. Compared with traditional learning methods relying on textbooks and static diagrams, the mixed reality application offers a more engaging and interactive learning experience, allowing students to observe microcontroller components from multiple perspectives and access detailed information through interactive triggers. This is consistent with Wu *et al.* (2013), who identified multi-perspective visualization of complex objects as one of the primary educational advantages of immersive technologies, and with Akçayır and Akçayır (2017), whose systematic review confirmed that enhanced visualization and interactivity are among the most frequently reported benefits of immersive media in educational settings.

The broader theoretical grounding for these findings is well established in the literature. Azuma *et al.* (2001) defined mixed reality systems as technologies that combine real and virtual objects in a shared three-dimensional space while supporting real-time interaction — all characteristics present in the developed application. Carmigniani and Furht (2011) further emphasized that such systems enrich the user's perception of reality through the seamless overlay of digital information, a principle directly reflected in how the application presents component information upon user interaction. Billinghurst *et al.* (2015) similarly noted that the spatial co-location of virtual and real objects in mixed reality environments provides a uniquely intuitive learning context that neither purely virtual nor purely physical media can offer. Radu (2014), in a meta-review of augmented reality in education, found that spatial and three-dimensional representations consistently produced stronger learning outcomes than two-dimensional alternatives, particularly for subjects requiring component-level understanding. Radianti *et al.* (2020) and Makransky and Petersen (2019) further corroborated these findings, reporting that immersive environments support the development of spatial reasoning and procedural knowledge in technical disciplines, though Makransky and Petersen (2019) also cautioned that cognitive overload remains a risk when interface complexity is not carefully managed. Mystakidis (2022) extended this discussion by arguing that immersive learning environments hold particular promise for higher education when designed around clear pedagogical objectives — a principle that guided the present study's adoption of the Luther–Sutopo development method.

Despite these promising results, several limitations warrant acknowledgment. The current system focuses primarily on component recognition and does not yet incorporate advanced simulation features such as real-time circuit assembly or program execution visualization. Furthermore, the sample size of ten students, while consistent with Nielsen's usability testing guidelines, restricts the generalizability of these findings to broader student populations. Future research is therefore recommended to involve a larger and more diverse participant pool, conduct comparative studies between mixed reality and other immersive technologies such as augmented reality and virtual reality, and integrate interactive circuit simulation modules — developments that may further strengthen the educational value of mixed reality learning systems in technical and vocational education.

5. Conclusion and Recommendations

A mixed reality-based learning application for microcontroller education was successfully developed using the Luther–Sutopo multimedia development method. The development process followed six systematic stages — concept, design, material collecting, assembly, testing, and distribution — ensuring that the application was built in a structured manner and aligned with learning objectives. The resulting system integrates three-dimensional visualization, interactive navigation, and an immersive learning environment, enabling users to explore microcontroller components more effectively than conventional learning methods allow. The application was successfully deployed on the Oculus Meta Quest 2 platform using Unity and Blender, and it functioned correctly in terms of navigation, interaction, and content presentation. Usability evaluation yielded an average score of 4.54 out of 5, corresponding to a success rate of 90.8%, placing the application within the "very feasible" category. Beyond feasibility metrics, the findings indicate that mixed reality technology appears to strengthen student engagement, spatial understanding, and interaction with microcontroller components in ways that static media cannot.

This study has several limitations, including the relatively small sample size and the absence of advanced features such as real-time circuit simulation. Future research is recommended to involve a larger number of participants, conduct comparative studies between mixed reality and other immersive technologies such as augmented reality and virtual reality, and integrate real-time circuit simulation features to further improve learning effectiveness. Whether MR genuinely outperforms its alternatives under controlled conditions remains an open question — and one worth pursuing.

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