Copyright © 2025 The Author(s)
Didaktika: Jurnal Kependidikan Vol. 14 No. 3 Agustus 2025

Evaluating Augmented Reality-Supported Project-Based Learning in Digital Economics and Business Education: An Experimental Study

Dede Rusmana[1], Fuad Abdul Fattah[2], Wening Patmi Rahayu[3], Rachmad Hidayat[4],
[1,2]Universitas Negeri Malang, Indonesia

[1]dede.rusmana.fe@um.ac.id

Abstract

Integrating Augmented Reality (AR) into Project-Based Learning (PjBL) was evaluated for its effect on undergraduates' critical thinking in a Digital Economics and Business course. A quasi-experimental design compared a control class (n = 40) and an AR-supported class (n = 34) over 16 meetings using the same syllabus; the experimental class used Assemblr Edu during project work. Critical thinking was measured with a 5-item test (0–100) administered pre and post-intervention and scored by external raters. Because Shapiro–Wilk tests indicated non-normality (all $p < 0,05$), Mann–Whitney U and Friedman tests were applied ($\alpha = 0,05$). Baseline equivalence held (pretest $U = 655,0$ and $Z = -0,276$, $p = 0,782$). After the intervention, the between-group difference remained non-significant ($U = 624,5$ and $Z = -0,612$, $p = 0,540$). Within-group gains were significant for both classes: control $\chi^2(1) = 24,641$, $p < 0,001$ (mean ranks pre 1,11 to post 1,89); experimental $\chi^2(1) = 12,500$, $p < 0,001$ (pre 1,21 to post 1,79). In short, PjBL improved critical thinking regardless of AR, and AR did not add a detectable short-term advantage. In this context, implementation should prioritize problem task alignment and sustained practice over technology adoption.

Keywords: *Augmented Reality, Business Education, Creativity, Experimental Study, Project-Based Learning*

Introduction

The Digital Economics and Business course is a foundational subject offered to students in the Business Education Study Program from Universitas Negeri Malang. The primary objective and goal of this course is to equip students with fundamental knowledge of business concepts, opportunities, and basic practices. Students are guided to understand how a business is planned and operated in a simple yet contextual manner. The course implementation has been supported by project-based assignments intended to help students apply theoretical knowledge through business planning activities. Nevertheless, the results of these student projects have fallen short of expectations. Many projects were completed as a formality, showing limited conceptual understanding and originality. This shows that the current teaching approach hasn't fully succeeded in encouraging students to stay motivated and actively get involved.

An overemphasis on expository delivery may reduce students' motivation and participation. Effective learning environments foster curiosity and active participation; well-designed activities promote durable understanding and transfer. This idea lines up with deep learning, which stresses understanding concepts thoroughly, connecting ideas together, and being able to use what they've learned in real-life situations. When students feel comfortable and interested, they tend to participate more. Using the right teaching tools and media can play a big role in making the learning experience more engaging and enjoyable. When aligned with instructional

objectives, AR can increase engagement and support the visualization of abstract or complex business processes through interactive simulations. AR turning difficult or abstract business concepts into clear, tangible images. This approach not only makes it easier to understand but also helps students remember what they learn. Integrating AR facilitating comprehension and retention. This study develops AR-based materials and evaluates their effectiveness within a PjBL framework focusing on critical thinking. This study aims to develop AR-based teaching materials specifically for the Digital Economics and Business course. The goal is to overcome the limitations of traditional project-based learning and improve student outcomes by making the learning process more stimulating and meaningful. Based on this idea, the study was carried out as an experiment to see how effective AR media is at strengthening project-based learning.

Augmented Reality (AR) superimposes computer-generated information on the physical environment in real time and is accessible via head-mounted or handheld devices. AR applications are accessible via head-mounted displays and handheld devices. Compared with conventional media, AR affords real-time spatial registration and user interaction that may enhance comprehension and task performance (Dijaya & Suprayitno, 2018; Kabir, 2024) In industries, AR is showing great promise for making tasks more efficient and speeding up training. For example, using AR with head-mounted displays during repair jobs helps workers do their tasks more precisely and quickly by showing step-by-step instructions right in their line of sight. This way, workers don't have to switch their attention back and forth between instructions and tools, making learning and doing much smoother (Septinaningrum, 2022; Tsang & Blevins, 2015), t's especially handy for hands-on or technical skills where quickly getting the hang of things is important. In education, AR is becoming a groundbreaking tool that can make learning more engaging. It helps students get a better grasp of difficult or abstract ideas by turning them into interactive 3D models, which they can explore and even manipulate themselves. (Kaplan, 2021a; Loureiro, 2020; Siriwardhana, 2021). In educational contexts, AR is increasingly employed to support motivation, conceptual understanding, and participation when aligned with pedagogical objectives, help students understand concepts better, and increase their involvement. It lets teachers show abstract or complicated ideas using interactive 3D models, which students can explore and manipulate themselves. This hands-on approach encourages active learning and helps students grasp the material more deeply.(Delgado, 2020; Wedel, 2020). When embedded through game-based or simulation activities aligned with learning goals, AR-supported tasks can improve affective engagement and participation (Barteit, 2021a; Egger, 2020; Slater, 2020). Also, using AR in methods like gamification or escape room-style activities promotes teamwork, problem-solving, and critical thinking skills. These kinds of activities encourage learners to work together to solve related challenges, making learning more purposeful. Overall, rather than simply adding visuals, AR provides an interactive, learner-centred modality that, when pedagogically aligned, can enhance engagement and retention (Scavarelli, 2021). Still, using AR isn't without its drawbacks. Some challenges involve needing special equipment, having technical know-how to create AR content, and covering fairly high expenses. Plus, many schools may lack the resources or infrastructure to implement AR on a large scale (Rauschnabel, 2021). Therefore, its implementation should be pedagogically appropriate, well-planned, and tailored to the needs of learners and the specific context to achieve impactful results. In conclusion, AR shows great potential to transform both education and training. In education, it supports greater motivation and comprehension, while in industry, it contributes to higher accuracy and efficiency (Kowalczuk, 2021; Makhataeva, 2020). To get the most out of it, you need careful instructional planning, proper training for users, and content that fits their specific context (Ashtari, 2020; Gerup, 2020; Kozinets, 2023).

Copyright © 2025 The Author(s)

Project-Based Learning (PjBL) is an experiential instructional approach that focuses on active student engagement through real-world projects (Salazar-Peña et al., 2023). nstead of passively receiving theoretical knowledge, learners in PjBL settings are challenged to apply concepts to solve authentic problems, often in collaborative teams (Bowen & Tech, 2019; Ling et al., 2024). This approach supports the cultivation of essential 21st-century competencies, such as critical thinking, communication, creativity, and collaboration. Through designing, managing, and delivering projects, students become more responsible for their own education and connect their classroom experiences to professional practice (Palatnik, 2022). The theoretical foundations of PjBL are grounded in constructivist and socio-constructivist perspectives, particularly the perspectives of influential educational thinkers. PjBL reflects experiential learning that cycle, which involves concrete experiences, reflection, conceptualization, and experimentation. Rather than passive reception of information through lectures, students are encouraged to learn by doing engaging with real-life tasks, reflecting on their actions, and adapting their approaches. In business and management courses, Project-based Learning (PjBL) is becoming more popular as a way to connect classroom ideas with real-world experience. It helps students get ready for the complex and often interdisciplinary challenges they'll face in today's jobs (Kuppuswamy & Mhakure, 2020; Pan et al., 2021). One of the biggest advantages of PjBL is that it closely mirrors real work situations. Unlike traditional teaching methods, PjBL involves tackling open-ended, real-world problems that often require teamwork and creative thinking. These projects sometimes include working with outside organizations like companies or government agencies, giving students a chance to gain practical experience and understand how workplaces operate (Basilotta Gómez-Pablos et al., 2017; Wang, 2023). Because of this, PjBL not only helps students learn theoretical concepts but also prepares them to handle the practical issues they'll encounter in careers related to business, management, and social sciences (Dias-oliveira et al., 2024). Another important part of project-based learning (PjBL) is how it helps students develop skills in working with others and reflecting on their experiences. In typical classrooms, students don't often encounter the kinds of interactions and disagreements that happen in real-world workplaces (Pérez-Escolar et al., 2021; Sormunen et al., 2023). PjBL creates a space where students can learn to see different viewpoints, work through disagreements in a positive way, and think about their own roles and biases. Instead of viewing conflict as a problem, students learn to see it as a chance to grow building qualities like openness, empathy, and maturity that are useful in professional settings. (Chattapadhyay, 2021; Cifrian, 2020; Miller, 2019; Yilmaz, 2020). The benefits of PjBL go well beyond just grades. As students engage with real-world tasks, make decisions, and reflect on what went well or not, they develop a kind of 'personal knowledge' that grows out of their experiences. Through talking and negotiating with teammates, they expand their understanding and improve their problem-solving skills (Beneroso & Robinson, 2022; Birdman, 2022; Kuppuswamy & Mhakure, 2020). These kinds of experiences can be truly revolutionary, shaping not just what they know, but also how they think, act, and approach their future careers (Owens, 2020). Even though Project-Based Learning (PjBL) offers many advantages, putting it into practice isn't without its challenges. Creating real-world projects can take a lot of time and resources, and it often takes good coordination between teachers, students, and sometimes even outside partners (Crespí, 2022; Ngereja, 2020; Wijnia et al., 2024). Plus, because project designs, how students are assessed, and how much freedom students have can vary so much, it might be harder to get consistent or fully effective learning results. Not every school has the right facilities or support systems in place to fully adopt PjBL, either. That's why careful planning, proper teacher training, and ongoing review are so important to make sure it works well and lasts over time. Overall, PjBL can be a really powerful way to improve higher education. It makes learning more

meaningful, practical, and reflective of real life (Belwal, 2020; Ricaurte & Viloria, 2020). When used well, it doesn't just help students build their thinking skills but also teaches them social and emotional skills they'll need outside the classroom. So, PjBL has a lot of potential to connect what students learn in class with the skills they need in the real world, preparing them to succeed in fast-changing, team-focused workplaces (Krajcik, 2023; Morais, 2021).

Critical thinking has become more and more important today, especially with how quickly our world is changing and how complicated things can get. Most people agree that it's a key skill that helps us solve problems, make smarter decisions, and act responsibly (Dias-oliveira et al., 2024; Yüce, 2023). But even though critical thinking is gaining attention in schools everywhere, there's no single, clear definition that everyone agrees on. Different fields and theories see it in their own way, which makes it tricky to come up with one standard method for teaching it effectively (Maor et al., 2023; Park et al., 2023). Usually, experts look at critical thinking from three main angles: philosophical, psychological-cognitive, and educational. The philosophical side focuses on qualities like curiosity, open-mindedness, and fairness traits a really good critical thinker might have. The psychological and mental process side considers how we analyze information, evaluate ideas, and draw conclusions (Dias-oliveira et al., 2024; Sk & Halder, 2020). And from an educational point of view, critical thinking is seen as a set of skills that can be learned step-by-step, especially in school settings. Each perspective provides valuable insights, but they also reflect the broader debate on whether critical thinking should be treated as a general skill applicable across all domains or as something that must be taught within specific subject areas and social contexts (Ugwuozor, 2021). This debate is often framed as a tension between generalist and specifist views. Generalists believe that about critical of thinking is a set of transferable skills and dispositions that can be applied in any context. In contrast, specifists argue that critical thinking is deeply contextual and must be developed within particular disciplines, cultures, or situations (Cáceres et al., 2020; Dekker, 2020; Prayitno et al., 2023). While generalist models such as the well-known have influenced the development of many educational tools and assessments, critics point out that these models can overlook the social and cultural dimensions of thinking critically. On the other hand, specifist approaches emphasize relevance and authenticity but may lack clarity when it comes to broader applicability. Teachers play a pivotal role in fostering students' critical thinking skills (Tang et al., 2020a). Their ability to teach critical thinking depends on two interrelated aspects: their own capacity for analytical thinking and their aptitude to design and deliver instruction that promotes critical thinking in learners. While much attention has been given to how teachers can teach critical thinking, there is a growing recognition of the need to focus on teachers' own critical thinking abilities (Ismail et al., 2018). Teachers who think critically are better equipped to reflect on their teaching, make informed pedagogical choices, and model critical thinking for their students. They also tend to be more adaptive and resilient in addressing educational challenges (Bennett et al., 2023; Goodsett, 2020).

Recent research shows that both Project-Based Learning (PjBL) and Augmented Reality (AR) can help boost students' motivation, engagement, and understanding on their own. Still, most studies tend to look at PjBL and AR separately, without really combining them into a single teaching approach. Also, past research mainly emphasizes how AR or PjBL benefit learning in general, without exploring how mixing the two could work specifically in Digital Economics and Business courses. There's a noticeable lack of studies that examine how using AR together with PjBL can nurture creativity, critical thinking, and entrepreneurial skills in business education. To address this gap, this study will develop and test an AR-PjBL approach in a Digital Economics and Business course, aiming to see how it influences students' motivation, deep understanding, and ability to apply what they learn in real-world situations.

Copyright © 2025 The Author(s)

This study builds on previous research by exploring a key question: How does implementing Augmented Reality (AR) in Project-Based Learning impact students' critical thinking skills in a Digital Economics and Business course? The main goal is to find out whether using AR in PBL is more effective than traditional project methods in helping students develop their critical thinking abilities. What's new about this research is its combined approach merging the engaging features of AR with the collaborative and inquiry-based nature of PBL specifically applied to the context of Digital Economics and Business. This kind of integrated approach hasn't been thoroughly examined before, especially in a hands-on, experimental setting focused on enhancing students' critical thinking skills.

Method

This study was conducted in the Business Education Study Program in Department of Management from Faculty of Economics and Business that university is Universitas Negeri Malang. The research approach used was quantitative, employing a quasi-experimental method. The quasi-experimental design was applied without random assignment of participants, as the sample groups were pre-existing. The participants in this study consisted of 74 students divided into two classes: Class A and Class B. Class A, with 40 students, was designated as the control group, while Class B, with 34 students, was the experimental group. Data were analyzed using nonparametric tests with the Friedman test in SPSS. he primary analytical approach employed in this study was the Friedman test, alongside Spearman's rho and Kendall's tau, to explore the relationships between the intervention and the corresponding pre-test and post-test scores. To provide a more robust analysis, additional nonparametric methods were also applied to assess differences across groups. Prior to these procedures, normality tests were performed to guide the selection of appropriate statistical methods. A significance level of $p < 0.05$ was set to determine whether nonparametric techniques were more suitable than their parametric counterparts. (Carvalho, 2019a; Mahmoudi et al., 2021a). As suggested in previous methodological research, when the data fail to satisfy normal distribution criteria ($p < 0.05$), it is recommended to employ more robust nonparametric techniques. In these cases, methods such as, the Friedman test and the Mann-Whitney U test, also the Wilcoxon signed-rank test are considered more appropriate due to their ability to handle non-normally distributed data(King & Eckersley, 2019).

The success of student learning in digital business planning was assessed during the testing phase using two sets of questions. The first set was given as a pre-test and the second as a post-test; each comprised 5 items with the maximum total score is 100, evaluated based on a standardized scoring rubric. The pretest was conducted under controlled conditions before the intervention, while the posttest was held once all sessions were finished. To keep the process fair and objective, the course instructors did not grade these assessments. Instead, external evaluators with relevant expertise in business education were appointed and provided with a rubric to guide their scoring. After the testing phase, all the data were systematically organized and analyzed using nonparametric statistical methods, including Friedman test, , Mann-Whitney U test, and Wilcoxon signed-rank test. All significance testing was done at $p < 0.05$ (Carvalho, 2019b; Mahmoudi et al., 2021b).

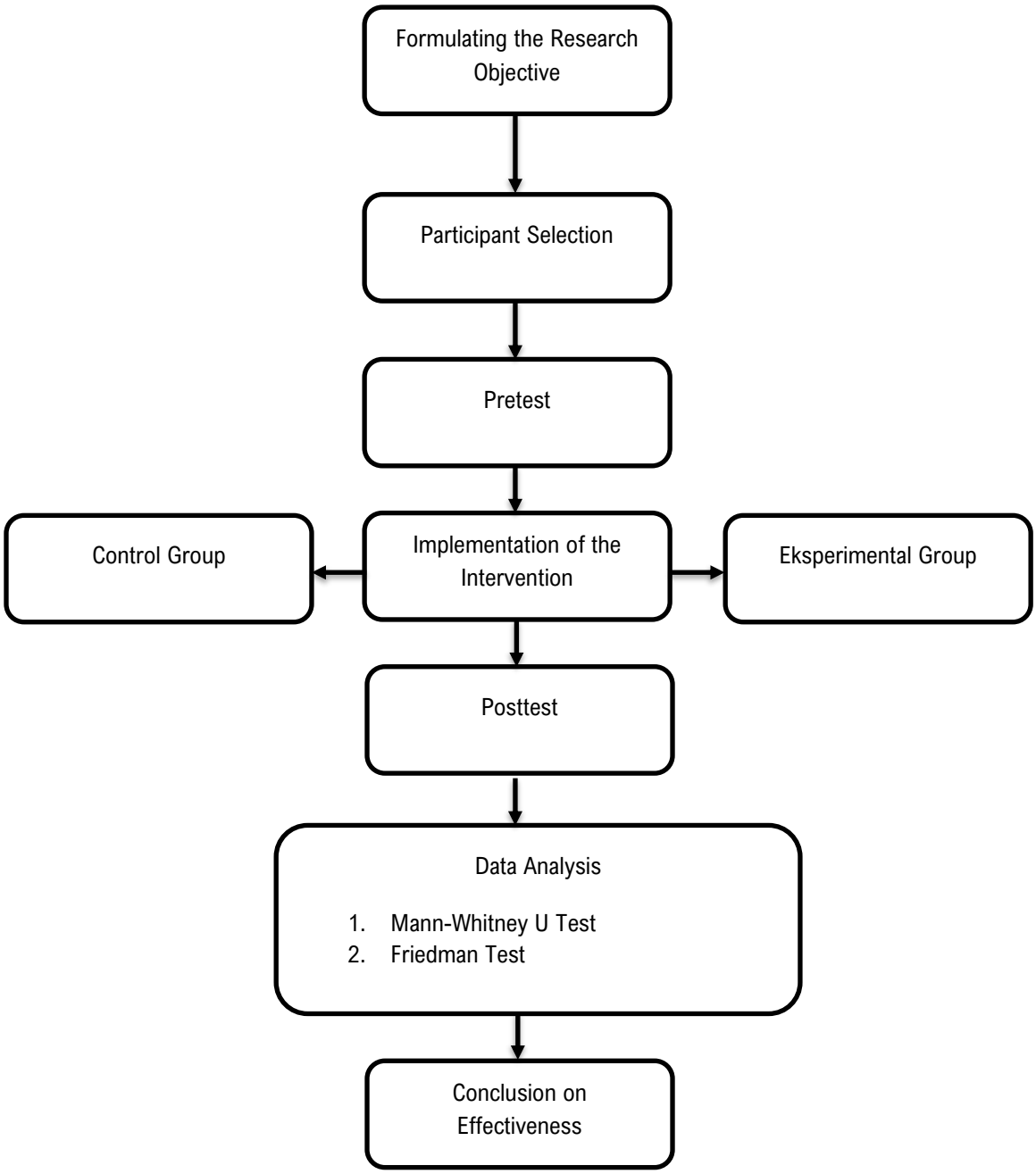


Figure 1. Research Phase

Figure 1 illustrates the procedural flow of the research. The primary aim from this research was to the examine the effectiveness of Augmented of Reality (AR) assisted learning on media in enhancing students' learning outcomes during a project based learning (PjBL) approach in the "*Digital Economics and Business*" course. A total of 74 undergraduate students from the Business Education program at Universitas Negeri Malang were involved in the study. Participants were divided into two pre-existing classes: Class A (control group, n = 40) and Class B (experimental group, n = 34). Both groups completed a pretest prior to the intervention. The test measured students' initial understanding of business planning concepts. To ensure objectivity, external evaluators assessed the results using a standardized rubric. The intervention was conducted over 16 class meetings. During meetings 1 to 8, both groups received identical instructional content delivered through conventional classroom methods. The control of group

Copyright © 2025 The Author(s)

that completed project assignments without the use of AR. The experimental of group that completed project assignments using AR-based instructional media accessed through the Assemblr Edu platform. After the completion of all sessions, a posttest was administered to both groups using the same format and rubric as the pretest. Again, the evaluation was conducted by independent assessors unfamiliar with the group assignments. Prior to conducting inferential statistics, normality tests (Shapiro-Wilk and Kolmogorov-Smirnov) were performed. As the data did not meet normal distribution assumptions, non-parametric tests were applied. Mann-Whitney U Test to compare posttest scores between control and experimental groups. Friedman Test to examine within group differences between pretest activity and posttest final scores. A significance of level from 0.05 was used that as the criterion for determining statistical differences.

Results

Product Augmented Reality Digital Economics and Business

The first step marked the initial step in developing an Augmented Reality (AR) based instructional media for the *Digital Economics and Business* course. In this stage, the researcher aimed to identify existing problems in the learning environment and explore learning needs aligned with student conditions and course objectives. Observations during the instructional process revealed that students often completed business project assignments as a mere formality, with minimal emotional or intellectual engagement. he projects produced so far show a limited grasp of core business concepts and lack creativity and innovation. Because of this, it's clear that we need to develop teaching materials that can make learning more interactive, engaging, and connected to real-world contexts. Using augmented reality (AR) as a teaching tool looks like a promising way to do this, since it can bring business ideas to life with interactive 3D simulations. This approach should help students understand concepts better, encourage them to participate more actively, and inspire them to come up with more creative and practical business ideas. This analysis provides a solid foundation for creating AR-based teaching resources that are meaningful, innovative, and aligned with the goals of the Digital Economics and Business course.

This project was mainly shaped by what we learned from the needs analysis, emphasizing how media could make it easier and more fun for students to grasp business ideas. We chose the key topics for our AR content from the Digital Economics and Business course, including what defines a business, different types of business structures, how products are made, how they're distributed, marketing strategies, and starting a business. These topics were brought to life in 3D using images, animations, and interactive features that students could access on their phones through the Assemblr.edu platform. During the design stage, we kept in mind methods like joyful learning and project-based learning to make the experience more engaging and focused on students. The media isn't just for sharing info; it's also a space where students can plan and run their own business projects in a real-world context. We made sure everything fit smoothly with the Semester Learning Plan (Rencana Pembelajaran Semester or RPS). To guide our work, we sketched out storyboards and basic layouts of the media interface early on. In the end, we created an initial plan for the instructional media that includes content, visuals, and interactive features, all designed to meet the intended learning goals.

During this stage, the focus was on designing both the visual elements and interactive features of the AR based instructional media to match the key topics of the Digital Economics and Business course. The researcher utilized Assemblr.edu to design a prototype media environment featuring 3D objects enhanced with supplementary information provided in the

form of text, icons, and interactive elements. The visual concept was based on a modern city landscape illustrating various economic activities and integrated business planning processes. The aim of this approach was to make it easier for students to understand interrelationships between components of the economic system such as households, companies, markets, and consumers in a more contextual manner. Additionally, the media visualized the stages of business planning in a logical sequence to support students' strategic thinking processes. The design prioritized joyful learning and adopted the PjBL approach, ensuring students were not only passive recipients of information but also actively exploring and connecting the material to their project work. Through mobile devices, students could easily access and interact with the visual elements in AR format.

The following are two sample visual designs from the developed media:



Figure 2. AR Display of Economic Activities Content



Figure 3. AR Display of Business Planning Content

Copyright © 2025 The Author(s)

The media was developed using the Assemblr Edu platform, which allows users to create interactive 3D visual content that can be accessed via mobile devices. The resulting media featured a virtual landscape populated with various interactive elements. Each element, such as buildings or location markers, was programmed to respond to scanning or touch gestures by displaying relevant instructional content. For example, when a user pointed their device at a numbered building, a description would appear explaining the function of that building in a business context such as management, marketing, operations, or finance.

Beyond providing interactive learning experiences, the media also supported students in creating their own storyboards. The interactions among the visual elements helped students understand the overall business process from production and distribution to customer service based on the illustrated simulation. A key feature of the media was the seamless integration between AR objects and supporting instructional content. When activated, certain elements directed users to supplementary materials such as text narratives, instructional videos, or reflective questions. This ensured the learning experience was not only visual but also thematically integrated with learning goals.The prototype was developed in alignment with the *Semester Learning Plan* (RPS) of the *Digital Economics and Business* course. All essential topics from the RPS were embedded into the AR elements in a contextual and applicable manner. Consequently, the media is expected to assist students in better understanding the course content through a more engaging and interactive visual approach.

The AR media can be accessed via the following barcode:

Figure 4. AR Media Access Barcode

It can also be accessed via the following link: https://asblr.com/yveeDj. Through this link, users can access the media in various modes to placing it in their surrounding space, viewing it in 3D, or activating it over a marker provided. This flexibility enhances the learning experience and aligns it with the learning material. Several interactive features are available within the AR media to support student engagement and learning effectiveness.

The development process established an augmented reality instructional medium for the Digital Economics and Business course with alignment to the Semester Learning Plan. The design team defined measurable learning objectives on conceptual understanding, process reasoning, and creative project planning. The platform selection favored Assemblr Edu because the platform provided accessible 3D dimensional assets, mobile delivery, and reliable interaction through touch and marker recognition. The scope definition identified core topics that included the nature of business, organizational forms, production and distribution flows, marketing strategies, and the sequence of venture initiation. The planning framework positioned project based learning as the organizing pedagogy for the integration of augmented reality within course

activities. The content design translated the scope into concrete learning scenes with explicit instructional functions. The storyboard specified objects, prompts, and expected learner actions for each topic. The interface plan adopted a one screen one objective principle to maintain simple navigation and controlled cognitive demand. The mapping matrix connected every augmented object to indicators of achievement and to tasks within the project cycle. The guidance prompts directed justification, comparison, and synthesis to support higher order reasoning during exploration of visual elements.

The media construction implemented the design choices within the Assemblr Edu environment. The visual layer presented a modern city landscape that represented economic subsystems and business functions in contextual form. The interactive layer attached textual explanations, icons, videos, and reflective questions to buildings and location markers. The activation rules triggered relevant content when a user scanned a marker or touched an object during a session. The sequence representation organized business planning as a logical chain that progressed from opportunity identification to marketing execution. The mobile deployment enabled immediate access in classroom settings and during independent project work. The validation procedures ensured pedagogical and technical soundness before classroom release. The content panel included a business education expert, an instructional design expert, and a learning media expert. The panel evaluated accuracy, clarity, relevance to the plan of study, and alignment with indicators of critical thinking and creativity. The panel applied a rubric and calculated a content validity index to support transparent decisions. The revision cycle clarified technical terminology, refined scene order, added contextual examples, and sharpened reflective prompts to emphasize causal reasoning and evidence use.

The technical validation examined compatibility, performance, and accessibility across common devices. The performance tests measured loading time, frame stability, touch responsiveness, and marker recognition under classroom conditions. The optimization steps reduced texture sizes, constrained polygon counts, and applied staged loading to maintain acceptable response time. The access strategy offered an alternative three dimensional view without markers for settings with weak connectivity. The embedded guide presented an onboarding checklist that explained entry steps, icon meanings, and completion of one task cycle. The formative trials tested usability and instructional flow with real learners. The one to one test engaged a small set of students who represented diverse levels of prior knowledge. The think aloud protocol captured points of confusion, misconceptions, and navigational friction during authentic tasks. The resulting adjustments enlarged touch areas, simplified overlay text, repositioned buttons, and added visual affordances that signaled possible interactions. The small group test examined collaboration dynamics, role distribution, and integration with the project sequence. The data collection employed observation sheets, field notes, screen recordings, a brief cognitive load scale, and a System Usability Scale questionnaire.

The field trial implemented the medium across a full class to examine feasibility and usefulness in routine instruction. The teaching package provided meeting objectives, task scenarios, scoring rubrics, and banks of reflective prompts for consistent delivery. The learning analytics recorded time on task, number of interactions, and completion rates for monitoring of engagement. The assessment compared process indicators with the quality of project artifacts using a rubric for value proposition clarity, production and distribution coherence, and marketing alignment. The reflective checkpoints consolidated understanding after each exploration by prompting short written justifications. The production phase completed the medium and the supporting documents for sustainable use. The package included an instructor guide, a student worksheet, and a map that connected augmented topics with course outcomes and assessments. The maintenance plan scheduled content review each semester, device

Copyright © 2025 The Author(s)

compatibility checks after operating system updates, and a user feedback channel for continuous improvement. The ethical protocol addressed informed consent, privacy of learning data, and equitable access for learners with limited devices through alternative materials. The final release delivered an augmented reality medium that supported active exploration, reduced initial cognitive barriers, and connected visual representations with decision making in business projects.

Normality Test

A normality test was performed in this study that to determine whether the distribution from scores in both the control and experimental groups followed a normal pattern. The normality check was carried out on two sets of data the pre-test and the post-test. The results of the normality test are presented below:

Tabel 1. Normality Test

Category	Group	Kolmogorov-Smirnov			hapiro-Wilk		
		Statistic	DF	Sig.	Statistic	DF	Sig.
Pre	0	0,239	40	0,000	0,820	40	0,000
	1	0,240	34	0,000	0,856	34	0,000
Post	0	0,256	40	0,000	0,894	40	0,001
	1	0,203	34	0,001	0,872	34	0,001

Source: Primary data processed in 2025

Table 1 presents the normality results for the data in this study. Normality was assessed using two measures: Kolmogorov-Smirnov and Shapiro-Wilk. The criterion for normal distribution was a significance (p) value >0.05. The results show that both Kolmogorov-Smirnov and Shapiro-Wilk tests yielded $p < 0.05$. This indicates that all four sets of data pretest and posttest scores from that both the control and or experimental groups were not normally distributed. Consequently, nonparametric statistical tests were used in this study.

Mann-Whitney Test (U Test)

This test was applied to determine whether this there were differences between two independent groups, given that the data were not normally about distributed. The following shows the results of the Mann-Whitney U test for the pretest scores:

Tabel 2. U Test Pretest

Test Statistics	
	Pre
Mann-Whitney U	655,0000
Wilcoxon W	1475,0000
Z	-0,276
Asymp. Sig. (2-tailed)	0,782

Source: Primary data processed in 2025

Based form the results above, the Mann-Whitney U test for the pretest scores comparing the control and experimental groups resulted in a p-value of 0.782, which is > 0.05. This indicates that there were no significant differences between the control and experimental groups before Augmented Reality was introduced. The following table presents the results of the Mann-Whitney U test for the post-test scores:

Tabel 3. U Test Posttest

Test Statistics	
	Post
Mann-Whitney U	624,500
Wilcoxon W	1219,500
Z	-0,612
Asymp. Sig. (2-tailed)	0,540

Source: Primary data processed in 2025

Table 3 above shows the results of the Mann-Whitney U test for the posttest scores of the control and experimental groups. The p-value was 0.054, which is > 0.05. This indicates that There was no significant difference between the control and experimental groups after the intervention with Augmented Reality. The results of both tests show that the participants were homogenous in their critical thinking skills at the outset. However, although there was some improvement after the intervention, it was not statistically significant. In other words, the progress made by the two groups was not significantly different.

Friedman Test

The Friedman test is used to the compare two or more measurements within the same of group when the data are not normally about distributed. In this study, the Friedman test was performed twice, first for the control group and then for the experimental group. For the control group, this test was applied to determine whether there were significant differences before and after the intervention in Project-Based Learning without the use of Augmented Reality. The following are the results:

Tabel 4. Friedman Test for Control Group

Test Statistics	
N	40
Chi-Square	24,641
df	1
Asymp. Sig.	0,000
Mean Rank Pre_0	1,11
Mean Rank Post_0	1,89

Source: Primary data processed in 2025

The table above shows a significance (p) value of 0.000. Based on this result (p < 0.05), it can be statistically concluded that there is a significant difference onto the pretest and posttest scores in the control group. Furthermore, the mean rank indicates that the post-test scores (Post_0) are > the pre-test scores (Pre_0), suggesting a significant improvement even without the use that Augmented Reality. Subsequently, the Friedman test was also conducted for the experimental group. The following are the results:

Tabel 5. Friedman Test for Experimental Group

Test Statistics	
N	34
Chi-Square	12,500
df	1

Copyright © 2025 The Author(s)

Asymp. Sig.	0,000
Mean Rank Pre_0	1,21
Mean Rank Post_0	1,79

Source: Primary data processed in 2025

The table above shows a significance (p) value of 0.000. Based on this ($p < 0.05$), we can statistically conclude that there is a significant difference between the pre-test and post-test scores in the experimental group. Furthermore, the mean rank suggests that the post-test scores (Post_0) are higher than the pre-test scores (Pre_0), reflecting a significant improvement after the implementation of Augmented Reality in the learning process.

Discussion

This result may be influenced by the strong role of the project-based approach (Project-Based Learning) already integrated into the course, the study habits of students in the control group, peer autonomy and support, the learning environment, and the students' motivation to learn (Aranzabal et al., 2022; Beier et al., 2019; Harms, 2015; Sasson et al., 2018). They were able to demonstrate that constructive learning, even without the use of advanced media, can help them understand the material and enhance their critical thinking skills once they have grasped the fundamental concepts (de Bie et al., 2015; Tang et al., 2020b).

Meanwhile, the experimental group that used AR media also demonstrated a significant improvement in critical thinking skills, with a Chi-Square value of 12.500 and $p = 0.000$. Although the statistical improvement was lower than that of the control group, the use of AR still made a positive contribution to conceptual understanding. he increase in average rank from 1.21 before the test to 1.79 afterward suggests that students were better able to understand the material after working with 3D media through AR. These findings emphasize how important it is to use the right instructional tools to help students grasp concepts and solve related problems more effectively. When comparing the control and experimental groups with the Mann-Whitney test, there weren't any major differences found in either the pre-test ($p = 0.782$) or the post-test ($p = 0.540$). This means that using AR media didn't show a clear short-term advantage over traditional methods. These results lead us to think more deeply about what's really going on. While AR is a tool that can help make abstract ideas more concrete, its success isn't just about the technology. It also depends on things like how long students use the media, the learning environment, how AR is incorporated into teaching, and whether students are motivated and ready to learn (Altmeyer, 2020; Cai, 2021; Chang et al., 2022; Khan, 2019). Another thing to think about with these findings is that people might be curious about AR technology simply because it's new. This means that while folks might be really interested at first, that enthusiasm doesn't always lead to a deep or lasting understanding of the concepts and skills involved in using it over time (Barhorst, 2021). This consideration becomes even more pronounced in fields that are more technical and require a comprehensive understanding, such as business. Unlike the exact sciences where outcomes are more deterministic and certain assumptions can be disregarded AR may be more effective in those disciplines due to their well-defined and predictable nature (Barhorst, 2021; Garzón, 2020; Thees, 2020)

In the context about project-based learning, AR can be viewed as a supportive tool that foster student engagement and critical thinking. It assists them in visualizing the entire sequence of business processes in a coherent and logical way, allowing for a more comprehensive understanding of how each step connects (Garzón, 2019; Ou Yang et al., 2023). This medium has the potential to be more effective if implemented on a sustained basis, alongside reflective

guidance and more in-depth project exploration (Dargan, 2023; Elmqaddem, 2019; Huang, 2019). It is crucial to conduct a thorough needs analysis to identify what students in a class truly require. The most suitable media may not necessarily be the most advanced; in some cases, students may respond better to more traditional or simpler methods. Although the results did not show a significant difference between groups, integrating AR into the learning process still holds strategic value. It can enrich the overall learning experience and foster active engagement, particularly in technology-based business education.

The insights from this study have meaningful implications for educators and curriculum developers alike. Incorporating AR-PjBL into Digital Economics and Business courses appears to be a promising approach for boosting students' critical thinking abilities. On a theoretical level, the findings reinforce constructivist views and emphasize the importance of engaging, student-centered learning methods in cultivating higher-order thinking skills. What's more, these results can help shape future teaching strategies and policy decisions aimed at integrating AR-PjBL into classroom settings. They also open up new avenues for research into technology-enhanced teaching methods at the higher education level. This study has some limitations that are important to honestly acknowledge. First, the sample size was quite small and only involved students from a single class in the Digital Economics and Business course, which means the findings might not apply to other classes, subjects, or schools. Second, the research was conducted over a relatively short period, so it might not reflect the long-term impact of AR-PjBL on critical thinking skills. Third, the study focused only on critical thinking and didn't look at other possible outcomes like creativity, teamwork, or motivation, which could also be affected by AR-PjBL. Besides, factors such as whether students had access to smartphones and AR apps might have played a role in how the program was experienced and how well it worked. Lastly, since the study used a quasi-experimental design, there’s a chance that other variables not accounted for could have influenced the results, making it harder to establish clear cause and effect relationships. Despite these limitations, they actually point us toward future research directions. For example, testing with a larger and more diverse group, running the program for a longer time, and exploring other outcomes can help us better understand what AR-PjBL can do.

Under both conditions, the analyses showed meaningful within group gains across the intervention, while the posttest comparison did not indicate a significant between group difference. The pattern aligns with contemporary theory that encourages a shift from media comparison questions to investigations of when and how augmented reality supports learning in specific instructional contexts (Buchner & Kerres, 2023). Implementation dosage and technology acclimatization plausibly moderated the augmented reality effect because novice users required time to establish routines and experienced initial cognitive effort during early sessions in the project cycle (Rahmat et al., 2024). Reviews of augmented reality design further show that impact depends on supportive guidance that connects visualization to generative learning activities, which reduces incidental load and strengthens transfer (Buchner & Kerres, 2023). Reports from engineering education additionally note that device stability, interaction modes, and the fit of applications to the working environment shape task performance during training, which can delimit short term gains in crowded classrooms (Barteit, 2021b).

Contextual constraints such as connectivity, device access, and uneven digital empowerment likely reduced the depth of augmented activities during collaborative work in routine sessions (Mkwizu & Bordoloi, 2024). Evidence from higher education also documents limited opportunities to experience augmented reality and persistent gaps in teacher preparation for technology use, which can dampen observable between group differences in short interventions (Mkwizu & Bordoloi, 2024). The practical implications support specific actions for instructors,

Copyright © 2025 The Author(s)

program leaders, developers, and institutions. Instructors can schedule an early orientation meeting to build operational routines, to explain interface actions, and to provide stepwise guidance that lowers initial cognitive demand during media use (Rahmat et al., 2024). Instructors can allocate augmented reality to topics that demand spatial and process visualization and can pair each activity with summarizing or explanation prompts that promote generative processing and deeper understanding (Duarte, 2020; Kaplan, 2021b; Ong, 2020). Program leaders can strengthen teacher digital competence through targeted workshops and micro credentials so that task design aligns augmented tools with explicit cognitive goals (Mena et al., 2023). Developers can prioritize simple interfaces, robust performance, and embedded guidance to support classes with diverse readiness levels (Rahmat et al., 2024). Course teams can combine augmented reality with project based and peer tutoring structures to sustain collaboration and communication skills while maintaining curricular focus (Arpan et al., 2024). Institutions can secure essential connectivity, device provision, and support services to enable inclusive participation across meetings (Mkwizu & Bordoloi, 2024).

The methodological implications guide the next evaluation cycle. Future evaluations can replace broad media comparisons with value added designs that vary instructional features within augmented environments and with learner treatment interaction designs that consider prior experience and strategy knowledge (Buchner, 2022). Reports can include transparent reliability and validity evidence for instruments and can document dosage and fidelity to clarify boundary conditions for the observed effects (Mena et al., 2023). In future studies, it would be great to include a bigger and more varied group of students so the findings can apply to more people. Also, trying out the intervention over a longer time might give us a better idea of how well it keeps impacting critical thinking in the long run. Plus, future research could look into using AR-PjBL to help develop other skills like creativity or teamwork, and maybe even use a true experimental setup to better control for outside factors.

Conclusion

The results indicate that Project-Based Learning effectively enhanced students' critical thinking skills, whether AR media were used or not. This underscores a practical implication for lecturers to provide meaningful learning experiences that allow students to be active and to explore collaboratively with their peers. Higher education institutions should recognize this opportunity and respond by designing appropriate instructional strategies within their curricula. Structural guidance may be a key factor in optimizing Project-Based Learning and improving graduates' quality. Project Based Learning improves student critical thinking in this context. Augmented Reality shows similar short-term outcomes compared with conventional activities. Instructional design quality drives the main gains in reasoning. Authentic problems, explicit reasoning scaffolds, and structured reflection strengthen learning outcomes. Targeted use of Augmented Reality addresses complex process visualization needs. Brief orientation sessions reduce cognitive load and access barriers. Long term studies examine Augmented Reality use across one semester or one year.

Delayed post-tests assess retention of critical thinking gains. Replication across Marketing, Operations, and Entrepreneurship courses tests transfer of effects. Dosage trials estimate the relationship between the number of Augmented Reality activities and gains in critical thinking. Comparisons of marker based and markerless designs evaluate usability and cognitive load. Comparisons of handheld and head mounted delivery evaluate user experience and learning efficiency. Moderator analyses test roles of prior achievement, spatial ability, and Augmented Reality familiarity. Cost effectiveness analyses estimate cost per unit improvement in critical

thinking. Cluster randomization, preregistration, and a priori power analysis support internal validity and interpretability. Equivalence testing or non inferiority testing informs policy relevant decisions. Use of validated instruments improves measurement quality of critical thinking. Furthermore, developing instructional media should consider various factors both internal and external that affect students' learning. Therefore, the focus should not be solely on adopting the latest technology, but on identifying and addressing the actual needs of the learners.

Practical implications for course delivery prioritize alignment between project tasks and explicit critical thinking indicators across the course. Instructors embed short written justifications after each activity to consolidate reasoning and guide feedback. Teaching teams provide a brief orientation to Augmented Reality to reduce cognitive load and device errors. Course plans allocate Augmented Reality to topics with high representational complexity such as process flows and interdependencies. Programs monitor access, device readiness, and time on task to ensure equity in participation. Departments supply low technology alternatives for students with limited devices to maintain inclusive practice. Assessment plans use validated critical thinking instruments alongside analytic rubrics to strengthen measurement and improvement. Schedules distribute Augmented Reality activities across multiple weeks to increase dosage and sustained practice. Instructor development provides micro training on facilitation of reasoning and delivery of high quality feedback. Course evaluations collect workload and usability ratings to identify friction points and support iterative refinement.

Acknowledgment

The author wishes to sincerely thank Universitas Negeri Malang for providing the research environment, and all respondents who generously participated and served as valuable sources of information for this study.

References

Altmeyer, K. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. *British Journal of Educational Technology, 51*(3), 611–628. https://doi.org/10.1111/bjet.12900

Aranzabal, A., Epelde, E., & Artetxe, M. (2022). Team formation on the basis of Belbin's roles to enhance students' performance in project-based learning. *Education for Chemical Engineers, 38*, 22–37. https://doi.org/10.1016/j.ece.2021.09.001

Arpan, M., Ambiyar, Ridwan, Nasution, A., & Rifdarmon. (2024). Augmented reality solutions by utilizing mobile technology for enhanced skill development. *International Journal of Interactive Mobile Technologies, 18*(20), 129–141. https://doi.org/10.3991/ijim.v18i20.50809

Ashtari, N. (2020). Creating augmented and virtual reality applications: Current practices, challenges, and opportunities. In *Conference on Human Factors in Computing Systems – Proceedings*. https://doi.org/10.1145/3313831.3376722

Barhorst, J. B. (2021). Blending the real world and the virtual world: Exploring the role of flow in augmented reality experiences. *Journal of Business Research, 122*, 423–436. https://doi.org/10.1016/j.jbusres.2020.08.041

Barteit, S. (2021b). Augmented, mixed, and virtual reality-based head-mounted devices for medical education: Systematic review. *JMIR Serious Games, 9*(3), e29080. https://doi.org/10.2196/29080

Basilotta Gómez-Pablos, V., Martín del Pozo, M., & García-Valcárcel Muñoz-Repiso, A. (2017). Project-based learning (PBL) through the incorporation of digital technologies: An

Copyright © 2025 The Author(s)

evaluation based on the experience of serving teachers. *Computers in Human Behavior, 68*, 501–512. https://doi.org/10.1016/j.chb.2016.11.056

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic project-based learning on attitudes and career aspirations in STEM. *Journal of Research in Science Teaching, 56*(1), 3–23. https://doi.org/10.1002/tea.21465

Bennett, B. L., Martin-Wagar, C. A., Boswell, R. G., Forrest, L. N., Perelman, H., & Latner, J. D. (2023). Skepticism of and critical thinking about media messages: Conflicting relationships with body dissatisfaction. *Eating Behaviors, 51*, 101820. https://doi.org/10.1016/j.eatbeh.2023.101820

Buchner, J. (2022). The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning, 38*(1), 285–303. https://doi.org/10.1111/jcal.12617

Buchner, J., & Kerres, M. (2023). Media comparison studies dominate comparative research on augmented reality in education. *Computers & Education, 195*, 104711. https://doi.org/10.1016/j.compedu.2022.104711

Cai, S. (2021). Effects of learning physics using augmented reality on students' self-efficacy and conceptions of learning. *British Journal of Educational Technology, 52*(1), 235–251. https://doi.org/10.1111/bjet.13020

Carvalho, I. A. (2019b). On the statistical evaluation of algorithmic's computational experimentation with infeasible solutions. *Information Processing Letters, 143*, 24–27. https://doi.org/10.1016/j.ipl.2018.11.003

Chang, H.-Y., Binali, T., Liang, J.-C., Chiou, G.-L., Cheng, K.-H., Lee, S. W.-Y., & Tsai, C.-C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education, 191*, 104641. https://doi.org/10.1016/j.compedu.2022.104641

Dargan, S. (2023). Augmented reality: A comprehensive review. *Archives of Computational Methods in Engineering, 30*(2), 1057–1080. https://doi.org/10.1007/s11831-022-09831-7

de Bie, H., Wilhelm, P., & van der Meij, H. (2015). The Halpern Critical Thinking Assessment: Toward a Dutch appraisal of critical thinking. *Thinking Skills and Creativity, 17*, 33–44. https://doi.org/10.1016/j.tsc.2015.04.001

Delgado, J. M. D. (2020). Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *Journal of Construction Engineering and Management, 146*(7), 04020073. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001844

Dias-Oliveira, E., Pasion, R., Vieira, R., & Lima, S. (2024). The development of critical thinking, team working, and communication skills in a business school – A project-based learning approach. *Thinking Skills and Creativity, 54*, 101680. https://doi.org/10.1016/j.tsc.2024.101680

Dijaya, R., & Suprayitno, E. A. (2018). Digital pamphlet of domestic tourism based on augmented reality: The promotion of Sidoarjo urban tourism site. *International Journal of Engineering and Technology (UAE), 7*(4), 392–395. https://doi.org/10.14419/ijet.v7i4.28.22618

Duarte, M. L. (2020). Learning anatomy by virtual reality and augmented reality: A scope review. *Morphologie, 104*(347), 254–266. https://doi.org/10.1016/j.morpho.2020.08.004

Egger, J. (2020). Augmented reality in support of intelligent manufacturing – A systematic literature review. *Computers & Industrial Engineering, 140*, 106195. https://doi.org/10.1016/j.cie.2019.106195

Elmqaddem, N. (2019). Augmented reality and virtual reality in education: Myth or reality? *International Journal of Emerging Technologies in Learning, 14*(3), 234–242. https://doi.org/10.3991/ijet.v14i03.9289

Garzón, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. *Educational Research Review, 27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Garzón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review, 31*, 100334. https://doi.org/10.1016/j.edurev.2020.100334

Gerup, J. (2020). Augmented reality and mixed reality for healthcare education beyond surgery: An integrative review. *International Journal of Medical Education, 11*, 1–18. https://doi.org/10.5116/ijme.5e01.eb1a

Goodsett, M. (2020). Best practices for teaching and assessing critical thinking in information literacy online learning objects. *The Journal of Academic Librarianship, 46*(5), 102163. https://doi.org/10.1016/j.acalib.2020.102163

Harms, R. (2015). Self-regulated learning, team learning and project performance in entrepreneurship education: Learning in a lean startup environment. *Technological Forecasting and Social Change, 100*, 21–28. https://doi.org/10.1016/j.techfore.2015.02.007

Huang, K. T. (2019). Augmented versus virtual reality in education: An exploratory study examining science knowledge retention. *Cyberpsychology, Behavior, and Social Networking, 22*(2), 105–110. https://doi.org/10.1089/cyber.2018.0150

Ismail, N. S., Harun, J., Aman, M., Megat, Z., & Salleh, S. (2018). The effect of mobile problem-based learning application DicScience PBL on students' critical thinking. *Thinking Skills and Creativity, 28*, 177–195. https://doi.org/10.1016/j.tsc.2018.04.002

Kabir, Z. S. (2024). Perceived subjective norms influence continuance intention in augmented reality platforms: A user experience study. In *30th Americas Conference on Information Systems (AMCIS 2024)*.

Kaplan, A. D. (2021b). The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. *Human Factors, 63*(4), 706–726. https://doi.org/10.1177/0018720820904229

Khan, T. (2019). The impact of an augmented reality application on learning motivation of students. *Advances in Human-Computer Interaction, 2019*, 7208494. https://doi.org/10.1155/2019/7208494

King, A. P., & Eckersley, R. J. (2019). Inferential statistics III: Nonparametric hypothesis testing. In *Statistics for Biomedical Engineers and Scientists* (pp. 119–145). Academic Press. https://doi.org/10.1016/B978-0-08-102939-8.00015-3

Kowalczuk, P. (2021). Cognitive, affective, and behavioral consumer responses to augmented reality in e-commerce: A comparative study. *Journal of Business Research, 124*, 357–373. https://doi.org/10.1016/j.jbusres.2020.10.050

Kozinets, R. V. (2023). Immersive netnography: A novel method for service experience research in virtual reality, augmented reality and metaverse contexts. *Journal of Service Management, 34*(1), 100–125. https://doi.org/10.1108/JOSM-12-2021-0481

Krajcik, J. (2023). Assessing the effect of project-based learning on science learning in elementary schools. *American Educational Research Journal, 60*(1), 70–102. https://doi.org/10.3102/00028312221129247

Makhataeva, Z., & Varol, H. A. (2020). Augmented reality for robotics: A review. *Robotics, 9*(2), 21. https://doi.org/10.3390/robotics9020021

Copyright © 2025 The Author(s)

Mena, J., Estrada-Molina, O., & Pérez-Calvo, E. (2023). Teachers' professional training through augmented reality: A literature review. *Education Sciences, 13*(5), 505. https://doi.org/10.3390/educsci13050517

Mkwizu, K. H., & Bordoloi, R. (2024). Augmented reality for inclusive growth in education: The challenges. *Asian Association of Open Universities Journal, 19*(1), 88–100. https://doi.org/10.1108/AAOUJ-09-2023-0113

Ong, S. K., & Nee, A. Y. C. (2020). Augmented reality-assisted robot programming system for industrial applications. *Robotics and Computer-Integrated Manufacturing, 61*, 101820. https://doi.org/10.1016/j.rcim.2019.101820

Ou Yang, F. C., Lai, H. M., & Wang, Y. W. (2023). Effect of augmented reality-based virtual educational robotics on programming students' enjoyment of learning, computational thinking skills, and academic achievement. *Computers & Education, 195*, 104721. https://doi.org/10.1016/j.compedu.2022.104721

Rahmat, R. W. O. K., Afera, C. N. S., Basri, N. A. H., Madzin, H., & Hod, R. (2024). A mobile augmented reality application for undergraduate medical students using a flipped classroom approach. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 33*(2), 151–159. https://doi.org/10.37934/araset.33.2.151159

Rauschnabel, P. A. (2021). Augmented reality is eating the real-world! The substitution of physical products by holograms. *International Journal of Information Management, 57*, 102279. https://doi.org/10.1016/j.ijinfomgt.2020.102279

Scavarelli, A., Arya, A., & McArthur, V. (2021). Virtual reality and augmented reality in social learning spaces: A literature review. *Virtual Reality, 25*(1), 257–277. https://doi.org/10.1007/s10055-020-00444-8

Septinaningrum, S. (2022). Developing of augmented reality media containing Grebeg Pancasila for character learning in elementary school. *Ingénierie des Systèmes d'Information, 27*(2), 243–253. https://doi.org/10.18280/isi.270208

Thees, M., Kapp, S., Strzys, M. P., Beil, F., Lukowicz, P., & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. *Computers in Human Behavior, 108*, 106316. https://doi.org/10.1016/j.chb.2020.106316

Ugwuozor, F. O. (2021). Determinants of critical thinking of trainee teachers: A production function approach. *Thinking Skills and Creativity, 39*, 100765. https://doi.org/10.1016/j.tsc.2020.100765

--- This page is intentionally left blank---