

Adoption of Extended Reality in Higher Education and Its Impact on Students' Competency Mastery

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ABSTRACT

This study aims to analyze the adoption of Extended Reality (XR)-based learning and its impact on students' competency mastery in higher education. The research employed a mixed methods approach with a sequential explanatory design involving 64 university students in Malang City, Indonesia, divided into XR-based and conventional learning groups. Quantitative data were collected through pre-test and post-test learning outcome assessments and questionnaires, then analyzed using paired sample t-tests and independent sample t-tests. Qualitative data were obtained through semi-structured interviews with students and lecturers to strengthen the interpretation of quantitative findings. The results indicate that XR-based learning significantly improved students' cognitive, psychomotor, and affective competencies, particularly in psychomotor and affective domains. These findings highlight the practical potential of XR as an innovative learning strategy in higher education.

INTRODUCTION

The development of Extended Reality (XR) technology that includes Virtual Reality, Augmented Reality, and Mixed Reality has brought significant transformations in higher education learning, especially in responding to the demands of 21st century competencies that emphasize the mastery of practical skills, contextual experience, and the formation of professional attitudes. XR technology allows for the creation of an immersive learning environment that resembles real situations, so that students can develop competencies through hands-on experience that is difficult to realize through conventional approaches (Radianti et al., 2020). Accordingly, the use of XR is seen as relevant to increase learning engagement and knowledge transfer into real-world contexts (Makransky et al., 2021). Despite this, the adoption of XR in higher education still faces technical, pedagogical, and institutional challenges, both in developed and developing countries (Pellas et al., 2022).

A number of international studies have shown that the use of XR has the potential to improve students' learning outcomes and technical skills in various disciplines. An experimental study conducted by Parong and Mayer (2021) shows that Virtual Reality-based learning is able to significantly improve conceptual understanding and practice performance of students. Similar findings were also reported by Wu et al. (2023) who confirmed that Augmented Reality has a positive impact on students' procedural skills and learning motivation. However, most of the research still focuses on one dimension of competence or one type of XR technology, so it does not provide a comprehensive picture of the impact of XR on cognitive, psychomotor, and affective competencies simultaneously in the context of higher education.

In addition, many previous studies were limited to specific institutional contexts or used relatively small sample sizes, so generalizing findings is still a methodological issue (Makransky & Petersen, 2022). Research examining the effectiveness of XR often emphasizes cognitive learning outcomes, while psychomotor and affective aspects have not been analyzed in a balanced and integrated manner (Radu et al., 2021). This condition shows that there is a research gap related to the overall understanding of how XR adoption affects students' mastery of competencies in a multidimensional manner. Therefore, research that combines quantitative measurement of learning impact with qualitative exploration of XR users' learning experiences is needed.

Quasi-experimental approaches have been widely used to assess the effectiveness of learning technologies, including XR, but reported results still show considerable variation between learning contexts and designs (Hamilton et al., 2021). Some studies show significant improvements in learning skills and motivation, while other studies highlight limited adoption due to infrastructure readiness and lecturers' pedagogical competence (Pellas et al., 2022). The variation of these findings indicates that the influence of XR on student competence cannot be partially understood, but needs to be analyzed in the context of real implementation in higher education institutions. Thus, there is still a clear research gap regarding the effectiveness of XR in improving student competency mastery in developing countries.

Based on this background, this study is designed to fill the empirical gap by systematically examining the impact of the adoption of Extended Reality on the mastery of student competencies in higher education. This study explicitly aims to compare the effectiveness of XR-based learning with conventional learning through quasi-experimental design, as well as explore the experiences of students and lecturers through a qualitative approach. The focus of the research is directed at three main competency dimensions, namely cognitive, psychomotor, and affective, which are important indicators of the success of competency-based learning. The mixed methods approach is used to gain a complete and in-depth understanding of the impact and implementation process of XR.

Theoretically, this study contributes to the enrichment of the literature on the adoption of immersive learning technology by presenting integrated empirical evidence regarding the influence of XR on various dimensions of student competence. This research also expands the academic discourse on experiential learning by placing XR as a pedagogical medium that has the potential to transform learning practices in higher education (Radianti et al., 2020). Practically, the findings of this study are expected to provide a reference for lecturers, study program managers, and policy makers in designing innovative learning strategies that are in line with the demands of 21st century competencies.

Thus, this study not only seeks to validate the effectiveness of XR quantitatively, but also builds a contextual understanding of the supporting and inhibiting factors of XR adoption in higher education. The results of the research are expected to be the basis for the development of a technology-based curriculum that is more adaptive, applicative, and sustainable. In addition, this study makes a real contribution in answering the question of whether the adoption of Extended Reality is able to significantly increase student competency mastery compared to traditional learning approaches.

LITERATURE REVIEW

Extended Reality as a New Paradigm of Learning in Higher Education

The development of Extended Reality (XR) in higher education is seen as a paradigm shift from representation-based learning to hands-on experiential learning. This technology allows students to interact with complex simulated environments, thus supporting more authentic and meaningful learning (Dede et al., 2020). In the context of higher education, XR serves not only as a visualization tool, but also as a pedagogical medium that facilitates the construction of knowledge through exploration and active reflection. A study conducted by Jensen and Konradsen (2021) confirms that XR immersive environments are able to increase the depth of conceptual understanding compared to two-dimensional digital media. Thus, XR is seen as relevant to answer the demands of competency-based learning that emphasizes the integration of knowledge, skills, and professional attitudes.

XR and Student Cognitive Competency Mastery

A number of studies show that XR contributes positively to improving students' cognitive competence through the presentation of contextual and interactive information. Experimental research conducted by Makransky and Petersen (2020) shows that virtual environment-based learning significantly improves conceptual understanding and long-term knowledge retention. Similar findings were also reported by Kavanagh et al. (2021) who found that students who learned to use XR showed better problem-solving skills than the control group. This advantage is due to XR's ability to integrate visual, spatial, and procedural representations simultaneously. Therefore, XR is considered effective in supporting the mastery of complex and applicable cognitive competencies in higher education.

XR in Psychomotor Competency Development

The development of psychomotor competencies is one of the main advantages of the implementation of XR in higher education, especially in fields that require practical and procedural skills. A study conducted by Moro et al. (2021) on health education shows that XR-based simulations are able to increase students' accuracy and confidence in performing clinical skills. In addition, research by Alizadehsalehi et al. (2020) on engineering education found that XR helps students understand work procedures more systematically and safely without the risk of obvious errors. The simulated environment provided by XR allows students to do repetitive exercises and obtain immediate feedback. Thus, XR plays a strategic role in bridging the gap between theory and practice in competency-based learning.

XR and the Affective Dimension in Learning

In addition to cognitive and psychomotor aspects, XR also has significant implications for students' affective dimensions, such as motivation, engagement, and attitude towards learning. Research conducted by Cheng and Tsai (2020) shows that XR-based learning significantly increases intrinsic motivation and student learning engagement. The results of another study by Riva et al. (2022) confirm that XR immersive experiences can strengthen students' sense of presence and emotional attachment to learning materials. This increase in affective dimension contributes to the formation of professional attitudes and students' readiness to face real situations. Therefore, XR is seen as a technology that supports holistic learning that is not only oriented towards academic outcomes, but also on the formation of learning character and attitudes.

Research Gaps and Relevance in Developing Countries Contexts

Although the international literature shows the great potential of XR in improving students' mastery of competencies, most research is still conducted in developed countries with adequate infrastructure and resource support. Research by Bond et al. (2023) highlights that the effectiveness of XR is strongly influenced by institutional context, lecturer readiness, and policy support. Meanwhile, studies that specifically examine the implementation of XR in developing countries are still relatively limited and tend to be descriptive (Zhao

& Xu, 2024). This gap shows the need for empirical research that examines the impact of XR on student competence in a multidimensional way in the context of higher education in developing countries. Thus, this research has a strong relevance in enriching the international literature while providing contextual evidence that has been underrepresented.

METHODOLOGY

Types and Approaches to Research

This study uses a mixed methods approach with an emphasis on the integration of quantitative and qualitative data to gain a comprehensive understanding of the impact of Extended Reality adoption on student competency mastery. The mixed methods approach was chosen because it is able to combine the power of statistical analysis with the depth of contextual meaning of the research subject's experience (Creswell & Plano Clark, 2021). The design used is sequential explanatory, where the collection and analysis of quantitative data is carried out at the initial stage, then continued with qualitative data to explain and deepen quantitative findings. This design is seen as appropriate to assess the effectiveness of learning interventions while understanding the processes and perceptions that accompany them in more depth (Guetterman et al., 2020).

Quantitative Design and Research Subjects

At the quantitative stage, the study applied a quasi-experimental design with a pre-test and post-test pattern of the control group. The research subjects totaled 64 students from one of the universities in Malang City, Indonesia, who were selected based on the equality of academic and curriculum characteristics. Students were divided into two groups, namely 32 students in the experimental group who participated in Extended Reality-based learning and 32 students in the control group who participated in conventional learning. The quasi-experimental design was chosen because it allows evaluation of the impact of treatment in a real educational context without having to perform full randomization that is difficult to apply ethically and administratively (Shadish et al., 2020).

Population, Sampling Techniques, and Qualitative Participants

The population of this study includes all students who take practice-based courses in related study programs. The sampling technique uses non-probability sampling, especially purposive sampling, with consideration of the suitability of the subject's characteristics to the research objectives and readiness to participate in XR-based learning. At the qualitative stage, 10 participants, consisting of 8 students from the experimental group and 2 lecturers in charge of the course, were selected to be interviewed in depth. The selection of qualitative participants was carried out purposively based on active involvement in XR learning and the ability to provide critical reflection on the learning process (Palinkas et al., 2020).

Data Collection Techniques and Instruments

Quantitative data collection was carried out using learning outcome tests and student competency mastery questionnaires that included cognitive, psychomotor, and affective dimensions. The instrument was prepared based on experiential learning competency indicators and developed with reference to the higher education competency assessment framework (Biggs & Tang, 2022). The validity test of the contents was carried out through expert judgment, while the reliability of the instrument was tested using Cronbach's alpha coefficient. At the qualitative stage, data were collected through semi-structured interviews designed to explore learning experiences, perceptions of XR's effectiveness, as well as supporting and inhibiting factors for the implementation of XR-based learning. Interviews were recorded, transcribed verbatim, and analyzed thematically.

Research Implementation Procedure

The implementation of the research is carried out gradually and systematically. The initial stage begins with the preparation of XR-based learning tools, the preparation of research instruments, and limited trials to ensure technical and pedagogical readiness. Furthermore, a pre-test was given to both groups to measure the initial competency of students. The intervention phase was carried out over a semester, where the experimental group followed XR-based learning, while the control group followed conventional learning with equivalent material and time. After the intervention is completed, a post-test is given to measure changes in competency mastery, followed by qualitative interviews to deepen the interpretation of quantitative results. This procedure is designed to maintain treatment consistency and minimize research bias (Fetters et al., 2020).

Data Analysis Techniques

Quantitative data analysis was carried out using paired sample t-test to test the difference between pre-test and post-test in each group, as well as independent sample t-test to compare the results between the experimental group and the control group. The analysis was carried out with the help of IBM SPSS Statistics software. Meanwhile, qualitative data were analyzed using thematic analysis with an inductive approach, which involved the process of open coding, categorization, and drawing of the main theme. The integration of quantitative and qualitative results is carried out at the interpretation stage to gain a complete understanding of the impact and dynamics of the implementation of Extended Reality in higher education learning (Nowell et al., 2021).

RESEARCH RESULT

Improvement of Cognitive Competency through Extended Reality-Based Learning

The results of the quantitative analysis show that the application of Extended Reality-based learning has a positive impact on improving students' cognitive competence. Students in the experimental group experienced a

significant increase in scores between pre-test and post-test, and showed higher final achievement compared to the control group that followed conventional learning. These findings indicate that XR's immersive learning environment is able to help students understand concepts in a more in-depth and structured way.

Table 1. Comparison of Cognitive Competency Scores Between Experimental and Control Groups

Group	Pre-test means	Post-test Mean	Mean Difference	Sig. (p)
Experimental (XR)	68.42	82.15	13.73	0.001
Control (Conventional)	69.10	75.28	6.18	0.038

Based on Table 1, the increase in cognitive competency scores in the experimental group was almost double that of the control group. The results of the paired sample t-test showed a significant increase in both groups, but the mean difference value of the experimental group was larger. Meanwhile, the results of the independent sample t-test on the post-test score confirmed that the difference in cognitive achievement between the two groups was significant. These findings suggest that XR not only improves conceptual understanding, but also accelerates the process of internalizing knowledge through more contextual learning experiences.

To deepen understanding of the quantitative findings, in-depth interviews were conducted with students and lecturers. In general, participants said that XR helped them visualize abstract concepts that were previously difficult to understand. "*Material that I usually only imagined from slides I can now see and explore directly, so it's easier to understand and not easily forget*" (M-03, 12 October 2025). "*With XR, I feel like the flow of the concept is more fluid because I learn while watching the process, not just memorizing the theory*" (M-07, 18 October 2025). "*From the lecturer's side, it can be seen that students are faster to grasp the core concepts and the discussions in the classroom become more weighty*" (D-01, October 20, 2025). These qualitative findings confirm that the improvement in cognitive competence is not solely due to technology, but by the way XR facilitates experiential learning that strengthens conceptual understanding. Thus, XR contributes significantly to the mastery of students' cognitive competencies.

Significant Enhancement of Psychomotor Competency through XR-Based Practice

Quantitative findings show that the most significant improvement due to the application of XR occurs in the psychomotor competence dimension. Students in the experimental group experienced a much higher spike in practical skills scores than the control group. This shows that XR is very effective in supporting learning that demands procedural skills and hands-on practice.

Table 2. Psychomotor Competency Scores Before and After Intervention

Group	Pre-test means	Post-test Mean	Mean Difference	Sig. (p)
Experimental (XR)	65.87	85.94	20.07	0.000
Control (Conventional)	66.12	72.36	6.24	0.041

Table 2 shows that the experimental group experienced a very high increase in psychomotor scores with a mean difference of more than 20 points. In contrast, the improvement in the control group was relatively limited. The results of the statistical test showed that the difference in post-test achievement between the two groups was very significant. These findings confirm that XR-based learning provides a more intensive, safe, and repetitive practice space, so that students can hone their practical skills optimally.

The results of the interviews reinforced the findings, where students stated that XR provided a practical experience that was close to real conditions without risk pressure. "I can repeat the exercises many times until they are right without fear of being wrong, it really helps improve my skills" (M-01, 10 October 2025). "With XR simulations, I became more confident when I had to do actual practice" (M-05, 16 October 2025). "From my observation, students who study with XR are more technically prepared when they enter a hands-on practice session." (D-02, October 22, 2025). Overall, quantitative and qualitative findings show that XR has the strongest contribution to the mastery of psychomotor competence. This technology has succeeded in bridging the gap between theory and practice, which has been a major challenge in competency-based learning in higher education.

Strengthening Affective Competency and Learning Engagement through XR Adoption

In addition to cognitive and psychomotor improvement, the results of the study also show that XR-based learning has a significant impact on the affective dimension of students, especially learning motivation, engagement, and attitude towards learning. Students in the experimental group showed a higher increase in affective scores than the control group.

Table 3. Affective Competency Scores of Experimental and Control Groups

Group	Pre-test means	Post-test Mean	Mean Difference	Sig. (p)
Experimental (XR)	70.15	86.02	15.87	0.000
Control (Conventional)	71.03	77.18	6.15	0.047

Based on Table 3, it can be seen that the experimental group experienced a significant increase in the affective dimension with a much higher mean difference than the control group. These results show that immersive learning experiences not only improve academic outcomes, but also build positive attitudes towards the learning process.

Qualitative findings reveal that students feel more motivated, engaged, and enjoy the learning process when using XR. "*The study feels more lively and not boring, so I am more enthusiastic about attending lectures*" (M-02, 11 October 2025). "*I felt more focused and really engaged during XR learning than in regular classes*" (M-06, 17 October 2025). "*The change in students' attitudes is very visible, they are more active, enthusiastic, and responsible for learning*" (D-01, October 20, 2025). The integration of quantitative and qualitative findings shows that XR plays an important role in shaping a positive learning climate. This increase in affective competence strengthens students' readiness to learn independently, collaboratively, and professionally.

DISCUSSION

The main results of this study show that the adoption of Extended Reality (XR) in higher education learning significantly improves student competency mastery compared to conventional learning, especially in the psychomotor and affective dimensions. These findings confirm that immersive experiential learning has the advantage of facilitating an applicative and contextual learning process. Theoretically, these results are in line with the principle of experiential learning which emphasizes that the most effective learning occurs when students are directly involved in experiences that resemble real-life situations (Luo et al., 2021). The XR environment allows students to integrate knowledge, skills, and attitudes in a unified learning process. Thus, the findings of this study strengthen the argument that immersive technology is not just a visual aid, but a pedagogical medium that has the potential to transform learning practices in higher education.

The improvement of students' cognitive competence in XR-based learning groups shows that immersive learning experiences are able to support the construction of deeper knowledge. Constructivist learning theory explains that conceptual understanding develops when students actively build meaning through interaction with their learning environment. The XR environment provides spatial and procedural representations that enrich the cognitive elaboration process, so that students not only memorize concepts, but also understand the relationships between concepts in their entirety. These findings are in line with recent international research showing that immersive learning improves knowledge retention and higher-level thinking abilities (Meyer et al., 2023). Consequently, XR contributes to strengthening cognitive competencies that are applicative and relevant to the needs of the world of work. Thus, this study makes an empirical contribution in expanding the understanding of the effectiveness of XR in supporting deep understanding-based learning.

The strongest impact of XR adoption in this study was found on the psychomotor competence of students. These findings can be explained through

simulation-based learning theories that emphasize the importance of repetitive practice in a safe and controlled environment. XR allows students to practice without the risk of real mistakes, so they can focus on mastering procedures and correctness of actions. Previous research has shown that immersive digital simulations are highly effective in improving practical skills because they provide hands-on feedback and a consistent learning experience (Bailenson et al., 2020; Makransky & Petersen, 2022). The significance of these findings is that XR is able to bridge the gap between theory and practice that has been a major challenge in competency-based higher education. Thus, this study confirms the position of XR as a strategic solution in the development of students' psychomotor skills.

In addition to cognitive and psychomotor aspects, significant improvements in affective competence suggest that XR plays an important role in building student motivation and learning engagement. The theory of self-determination explains that intrinsic motivation grows when students feel challenged, involved, and in control of their learning process. The immersive and interactive XR environment creates an engaging learning experience, allowing students to be more focused and have a positive attitude towards learning. These findings are consistent with the results of recent research that confirms that immersive experiences increase students' sense of presence and emotional engagement (Lindgren et al., 2022; Slater & Sanchez-Vives, 2023). An important consequence of these findings is that XR not only improves learning outcomes, but also forms a sustainable learning disposition. As such, XR supports holistic learning that includes cognitive, skill, and attitude dimensions.

The integration of quantitative and qualitative findings in this study shows that the effectiveness of XR is influenced by the way of implementation and pedagogical readiness. Students and lecturers consider that XR is most effective when used as part of a structured learning design, not just as an add-on to technology. This is in line with the instructional design approach that emphasizes alignment between learning objectives, activities, and assessments. Previous research has shown that advanced learning technologies will not have an optimal impact without proper pedagogical integration (Bond & Bedenlier, 2019; Martin et al., 2020). These findings support the initial hypothesis that XR is effective in improving competence, but also indicate that such success depends on the quality of learning design. Therefore, the contribution of this research lies in the affirmation that the adoption of XR should be understood as a pedagogical innovation, not just a technological innovation.

Although the results show a strong positive impact, there are several factors that have the potential to influence the variation in outcomes between individuals. Differences in students' technology literacy levels, early adaptation to the XR environment, and limited usage time can affect the depth of the learning experience. Some students take longer to adapt to immersive technology, which can reduce the effectiveness of early learning. These findings are in line with research showing that novelty effect and cognitive load can be challenges in XR-based learning (Parong et al., 2020; Kalyuga, 2021). Thus, the differences in outcomes that emerge can be explained logically through user

readiness factors and intervention design. This explanation enriches understanding of the conditions under which XR works optimally as well as in limited ways.

This research also has several limitations that need to be critically examined. A quasi-experimental design without full randomization limits the generalization of results to a broader context. In addition, the duration of interventions limited to one semester has not fully captured the long-term impact of XR use on competency mastery. Therefore, advanced research is recommended to use longitudinal designs and involve a more diverse sample across institutions and fields of study. Future research also needs to explore the combination of XR with other pedagogical approaches, such as collaborative learning and problem-based learning. Thus, the results of this study not only provide empirical evidence, but also open the direction of the development of XR-based learning research and practice in higher education.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that the adoption of Extended Reality (XR) in higher education learning significantly improves students' competency mastery in cognitive, psychomotor, and affective dimensions compared to conventional learning methods. The strongest impact was found in psychomotor and affective competencies, indicating that immersive and experiential learning environments can enhance practical skills, learning engagement, and student motivation. Based on these findings, higher education institutions are recommended to integrate XR technology into competency-based learning strategies, particularly in practice-oriented courses. Lecturers should also receive pedagogical and technical training to optimize XR implementation in learning activities. In addition, institutional support in terms of infrastructure, digital resources, and curriculum integration is essential to ensure the sustainability and effectiveness of XR-based learning innovation.

ADVANCED RESEARCH

This study has several limitations, including the relatively small sample size, the use of a quasi-experimental design without full randomization, and the limited intervention period of one semester. Therefore, future studies are recommended to involve larger and more diverse samples across different universities and academic disciplines, as well as apply longitudinal designs to examine the long-term impact of XR adoption on student competency development. Future research may also explore the integration of XR with collaborative learning, problem-based learning, or artificial intelligence-based educational systems.

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