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THE EFFECTS OF EXTENDED REALITY TECHNOLOGIES IN STEM EDUCATION ON STUDENTS' LEARNING RESPONSE AND PERFORMANCE

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Abstract. *STEM education is a crucial learning area to understand important concepts and gain 21st-century skills in different disciplines, explore scientific knowledge, and solve problems in daily life. However, research in STEM education is scarce on extended reality technologies. This research examined the effects of extended reality integrated STEM on students' learning response and performance. A quasi-experimental research design was used to find answers to the research questions. The same lecture taught the experimental and control groups but preceded STEM experimental activities at a different time and with distinct instructional strategies and teaching aids. The participants were students in two classes at a university in Taiwan. The research results showed that students in the experimental group applying extended reality-integrated STEM had better learning responses than students in the control group using teaching materials. The results also showed that students in the experimental group learning with an extended reality system could apply the STEM curriculum knowledge acquired in classes and reflect the learning outcomes on the test assessment for better learning performance than students in the control group. In addition, the results revealed that good learning responses could enhance students' higher learning performance. In light of the results, educational implications are made.*

Keywords: *extended reality, STEM education, learning response, learning performance, experimental research*

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Introduction

The 21st century is a technology-driven era, and the information network of the global village makes science and technology education an important area of learning for students. The goals of the curriculum include fostering the interest and passion for science exploration and the habit of active learning, learning the exploration and basic competence of science and technology, applying what is learned to present and future life, cultivating the attitude of protecting the environment, valuing resources and respecting life, cultivating the ability to communicate and express oneself with people, teamwork and harmony, cultivating independent thinking and problem-solving skills and stimulating creative potential, and awareness and exploration of the interaction between people and technology. Policy and reform documents in STEM education emphasize that science education not only focuses on the teaching of scientific knowledge but regards the cultivation of people's basic scientific ability as an important task, and expects people to be able to understand the contribution and limitations of science and technology to human beings, recognize the crucial concept and principles of science and technology, explore the commonalities and ambiguities, and apply scientific knowledge and scientific thinking to deal with personal life, solve problems, and even develop the potential to create new products for the benefit of people.

The new developments and advances have led to using artificial intelligence technologies in education. Until the advent of new technologies, lectures had to follow the schedule to arrange and design student teaching concepts in the form of narratives (Yannier et al., 2020). However, such a teaching method was a one-sided teaching mode that could easily lead to students being unwilling to interact with new knowledge and seeming to have a negative learning attitude toward expertise. STEM, the abbreviation for science, technology, engineering, and mathematics, is promoted internationally mainly to help people grasp and present multidimensional skills for real-world problems (Lee & Kim, 2021). Meanwhile, STEM encourages students to engage in hands-on learning to improve their understanding of math and science. It also encourages students to pursue engineering and science careers to maintain national industrial competitiveness worldwide

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(Andrews et al., 2021). Researchers have integrated STEM into artificial intelligence courses. According to the research results, STEM-based artificial intelligence courses have promoted and improved students' application of artificial intelligence (Lin et al., 2021). This study applied extended reality in teaching to help users learn through practice, understand the teaching content more precisely and deeply, and effectively promote achievement, the motivation to accept new knowledge, and the ability to acquire knowledge. At the same time, it can improve the insufficient interaction in the previous learning process. Therefore, this study explored the integration of extended reality into STEM regarding learning responses and performance, expecting that applying extended reality to the classroom experience and learning helps students achieve better learning performance.

Extended Reality and STEM Education

Extended reality (XR) is a general and integrated concept covering characteristics of virtual, augmented, and mixed reality (Altmeyer et al., 2020). The characteristics of virtual reality are to apply 3D virtual space to replace the real environment and provide users with an immersive experience and realistic effect (Karampelas, 2021). The characteristics of augmented reality are to augment virtual objects in real scenes for the users' interaction (Altmeyer et al., 2020). On the other hand, the characteristics of mixed reality are to stack virtual objects in the current world and emphasize crossing applications between virtual reality and augmented reality (Lee, 2021). XR could be defined as applying all real and virtual technologies to the interaction through the man-machine interface or appropriate hardware system equipment; meanwhile, there is a cross-relationship between the virtual and real environment in extended reality (Huang et al., 2020).

STEM integrates areas of science, technology, engineering, and mathematics, emphasizes the implementation of interdisciplinary concept teaching among various subjects, and allows students to master the curriculum concept for applications (Lee & Kim, 2021). Meanwhile, STEM encourages students hands-on to learn through the above routes (Lin et al., 2021). Benyeogor et al. (2021) emphasized that STEM should be the model integrating disciplinary theories with hands-on for students to comprehend and solve problems so that students could present the practical application and development skills for STEM teaching. Through hands-on, students comprehended and constructed learning impressions in the implementation process to deepen their cognition and avoid being unable to acquire and apply the technology by simply reciting theories from books. From the experiment of STEM robot coding, Xu and Wang (2022) concluded that teaching with different types of STEM activities would result in junior and senior high school students maintaining a positive tendency to STEM. Besides, students with highly positive STEM tendencies might be more interested in STEM-related jobs in the future. Jiang et al. (2022) mentioned that, in modern society, citizens were gradually requested to present professions integrating knowledge and technology into STEM to solve problems in reality; therefore, students should be reinforced with the ability to integrate interdisciplinary concepts and skills.

Extended reality is currently broadly applied to subject teaching as the visual medium to provide a high-interaction virtual learning environment for learners and offer users an immersive experience in the teaching process to vastly reduce the probability of being dull in classes (Hu-Au & Okita, 2021). For example, Benyeogor et al. (2021) stated that the existence and emergence of extended reality resulted in new definitions of teaching media and teaching aids. Many researchers studied the phenomena and influenced learners in immersive simulated learning environments. When the simulated world could accurately realize rendering technology was created and the cognition of compound illusion was output, learning response would be guided in the highly changeable virtual teaching world. Di Natale et al. (2020) conducted a systematic review of empirical research aiming at extended reality immersive technology. They revealed that extended reality immersive technology could support STEM experiments to induce further students' interest in STEM material or teaching aid systems. The core advantage lies in users acquiring real-time experience that could not be reached in the real world. A unique experiential learning response enhanced students' enthusiasm and participation (Okonkwo & Ade-Ibijola, 2021).

Gao et al. (2020) indicated that group learning with extended reality integrated STEM outperformed members in the other two groups on learning memory, positive emotion, and report participation. It was considered in the research that the application of extended reality integrated STEM could present better learning performance than conventional teaching and digital video teaching. Liu et al. (2020) preceded a quasi-experiment in which students in the experimental group applied extended reality to the STEM curriculum while students in the control group learned with conventional materials. Their results revealed that students in the experimental group outperformed the control group in learning performance and participation. In another research, Xu and Wang (2022) proposed

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the training environment of an immersive extended reality engineering laboratory to provide students with experience in a natural laboratory. According to them, the advantage of an immersive extended reality learning environment was providing a simple but highly secure experiment course, which could present identical engineering experiment content as in reality, for restoring the experience and interaction process. The research data revealed the positive learning effect, achievement, and specific practice experience of STEM from the immersive extended reality system (Theodoropoulou et al., 2020).

Guo et al. (2021) developed an extended reality mobile device for the study. The research showed that extended reality could effectively support science learning response and cultivate scientific inference skills in STEM. The study also revealed that extended reality could change abstract science concepts in STEM into tangible ones to appear in fascinating learning situations and overturn the subject education in STEM. Jiang et al. (2022) noticed that integrating emerging technology and visualization tools into STEM teaching aids could effectively induce students' participation in STEM classes, enhance the willingness to contact STEM, induce a better learning response, and promote learning performance in STEM. Promoting and cultivating students with the above features could have them present STEM skills required in the new century. Klingenberg et al. (2020) proposed that STEM-based digital learning websites displaying dialogic teaching and providing students with adaptive teaching modes could enhance students' self-directed learning experience and vastly improve students' learning response and learning performance in STEM (Petrov & Atanasova, 2020).

Extended Reality Implementations in Science Education

XR encompasses various technologies through virtualization and focuses on developing augmented reality (AR) by providing virtual information about the real world and virtual reality (VR) by simulating an environment that replaces reality. Since the use and implementation of XR technology in education are relatively new and is one of the research topics emerging in the science education literature, this section presents the results of previous studies focusing on AR and VR in STEM education at the undergraduate level.

For example, Liou et al. (2017) examined the efficacy of 2D images derived from VR and AR systems in an inquiry-based astronomy course. According to their findings, students in the AR group performed significantly better in terms of learning performance and task performance than those in the VR group. Consequently, these results suggested that AR technology assisted students in their lunar phase course. "Ease of use" and "intention" of acceptance showed no significant differences between the two groups, whereas "usefulness" and "attitude" revealed significant differences. Learners can easily integrate virtual objects and real environments with the AR system's features to reduce cognitive load and enhance their education. Ibanez et al. (2017) examined the effects of using an augmented reality-based simulator in a conventional classroom setting. The participants were 112 physics undergraduates enrolled in a Spanish college. Students could understand how magnetic fields interact with charged particles by viewing their three-dimensional trajectories. Their findings demonstrated that augmented reality technology increased student motivation. Artun et al. (2020) conducted a survey to explore the impact of virtual reality-enhanced laboratory activities on the science process skills of undergraduate science students who want to become lecturers. The study used the Google Expeditions app's VR environments and smartphone-compatible headsets to teach physics, chemistry, and biology concepts. The findings revealed a significant increase in test scores of the experimental group compared to the control group. Lee and Shea (2020) aimed to identify disparities between two pre-service elementary school lectures in a virtual reality learning platform. The participants were asked to assess, design, and appraise virtual reality applications (VR) in a three-stage process. The findings revealed that elementary school lectures exhibited increased confidence in teaching science through computer-based technologies after the intervention. Additionally, the PSETs responded positively towards their VR experiences and regarded VR applications as supplementary teaching tools. The majority of PSET teams were able to produce creative VR learning materials, which boosted their self-efficacy.

In a recent study, Lin et al. (2021) studied how non-engineering students performed in various aspects of artificial intelligence (AI). They found that students who had a good understanding of AI also showed an awareness of AI ethical concerns. Additionally, the researchers discovered that a STEM-based AI curriculum could enhance awareness of AI ethical issues in students with low AI knowledge levels. They recommended that lectures teaching general education courses incorporate their method to teach AI knowledge. Another study by Zatarain-Cabada et al. (2023) explored how web-based extended reality technologies could be used as a learning tool to teach physics. Students were provided didactic material on kinematic and dynamic concepts using an experimental process

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incorporating extended reality. The study found that both virtual and extended reality technologies significantly impacted motivation.

Aim

While studies in the literature have focused on the effectiveness of augmented and virtual reality on student performance; no study has examined student learning responses and performance at the undergraduate level. Only a few studies (Theodoropoulou et al., 2020; Zatarain-Cabada et al., 2023) have been conducted on extended reality in STEM education in the current literature. However, none of these studies have examined the effects of STEM education's extended reality on participants' learning responses and performance.

Therefore, this research determined the effects of extended reality-integrated STEM education on student learning responses and performance. The main contribution of this study is to present the design and implementation of extended reality-integrated STEM education. The research questions of this study were as follows:

1. What are the effects of extended reality integrated STEM on students' learning response and learning performance?
2. What are the effects of learning response on learning performance?

Research Methodology

Research Design

This study employed an experimental research design to examine the effects of extended reality-integrated STEM education on student learning responses and performance. A control and experimental group design was used to answer the research questions and evaluate the effects of extended reality education on student learning responses and performance. In experimental studies, researchers collect data to ensure that the participants receive the benefits of treatments. This kind of study may involve administering a specific treatment to an experimental group so that the participants eventually receive the beneficial treatment (Creswell, 2009). The research was conducted between September and December months in 2022.

Participants

The study involved 102 undergraduate engineering students from two classes at a public research university in Taiwan. The participants were selected through a convenient sampling method and comprised 75 males and 27 females, with an average age of 20.6. The participants were first-year students from an engineering college. The participants indicated that they used computers and smartphones before participating in this research. The participants approved the participation in this research. All of them participated voluntarily. They signed a consent form voluntarily to participate in the present research. All participants had basic skills in computers. Two lecturers taught the class.

Procedures

In a quasi-experimental design, the participants were split into two groups. The experimental group consisted of 51 students, while the control group had 51 students. The same lecturer taught both groups, but the STEM experimental activity was introduced at different times and with different teaching methods and aids. In the experimental process, students in the experimental group were taught the instructional strategy of extended reality integrated STEM to the experimental activity so that students could be engaged in the extended reality learning environment to comprehend STEM courses. On the other hand, students in the control group studied with computers, course materials, and teaching aids, e.g., textbook briefings and digital teaching films. Students in both groups had to follow the learned STEM content to achieve the learning tasks.

In the first week, before the teaching activities in the formal curriculum, the lecturer introduced the process of the 18-week experimental activity and the learning tasks for students to understand the course practice and explained the learning objectives of STEM teaching based on extended reality. After this introduction, the lecture administered the pre-tests to the experimental and control groups to determine the differences in prior knowledge of STEM between the two groups.

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The STEM teaching in this study was practiced three hours per week during weeks 2-17. The lecturer taught the experimental group with extended reality integrated STEM for instructional activities. The lecturer explained using the extended reality system and the corresponding learning units and objectives. The lecturer used the extended reality system during the experimental activities STEM. With the real-time evaluation, the lecturer could provide feedback to the participants on the STEM activities in the study to create a good learning environment so that the students could understand the error and clarify the correct concept for inference and evolution.

In addition, the effects of extrinsic factors in this study were kept as low as possible, and the experimental time was limited. In addition, the smooth process before the formal experiment was confirmed to ensure the smooth process of the STEM experiment. For the control group, the lecturer used computers, course materials, and teaching aids, including textbook instruction and digital instructional films, and applied didactic instruction to STEM experimental activity in the classroom. Students in both groups who had questions in class could actively ask the lecturer. Meanwhile, all instruction and experimentation were conducted in the allotted time to minimize the impact of extrinsic factors and ensure the accuracy of experimental data.

The teaching materials in this study aimed for students to learn basic knowledge of artificial intelligence while cultivating AI application skills. The design of the activities and the flow of the three AI learning units, introduction to features, unsupervised learning, and supervised learning, were developed in this study. Students in the experimental group applied extended reality AI teaching systems to learn and complete all AI learning systems. The students in the control group completed the experimental courses using computers and teaching materials. Meanwhile, students in both groups were assessed for their learning effectiveness and the difference in learning perception after completing the learning tasks. The AI materials for augmented reality and the tests for the students in the experimental group were developed following the interdisciplinary concepts of STEM.

Lecturers could comprehensively integrate science, technology, engineering, and mathematics concepts into instruction and application. The STEM interdisciplinary teaching concepts used in the teaching materials are (1) Science: the ideas of characteristics and labels were integrated into fruit science in the "Introduction to Characteristics" unit of the AI teaching materials so that students can understand the characteristics (features) and differences (labels) of different fruits. (2) Technology: the "Supervised Learning" unit of the AI teaching materials enabled students to apply AI concepts well and combine technology applications to solve the set tasks. The comprehensive concept of supervised learning was integrated into extended reality technology so that students could collect features by scanning feature cards to achieve the application of supervised learning and complete the AI supervised learning unit and technology knowledge teaching activity. (3) Engineering: the unsupervised learning unit was designed for students to apply the concept of engineering assembly to collect the features of different fruit labels to complete the unsupervised learning units. (4) Mathematics: Some questions combined parts of the calculation ideas with AI concepts in the test paper. For example, the AI concept was integrated with mathematical concepts so that students could become familiar with the AI knowledge and use the calculation logic to calculate the number of features of two different objects with the same labels, as well as review the core concept of AI and promote students' computational logical thinking.

In the 18th week of the experiment, the lecturer conducted a post-test for the experimental and control groups and STEM learning response questionnaires to discuss the difference between extended reality and STEM in learning performance and learning response. Students in both groups completed post-test questionnaires after completing the learning activity. It was observed that approximately 20 minutes were adequate to complete the questionnaires and survey. The experimental process was conducted between September 15 and December 15, 2022.

Data Collection Tools

The experiment tools applied to this study contain the learning response and performance questionnaires.

Learning Response Questionnaire

The learning response questionnaire for this study refers to the questionnaire designed by Chang and Chen (2020). Dimensions of "organization," "clarification," "repetition," "supervision," "concentration," "effort," and "teaching aid system" are discussed in the questionnaire. The learning response questionnaire was used to review and discuss the difference in the learning response to STEM curriculum between the experimental and control groups and further discuss factors in the result. This study used a course perception questionnaire developed by Chang and

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Chen (2020). The questionnaire included four dimensions: Learning Materials, Lecturer's Instruction, Administrative Service, and Learning Activity. The questionnaire contained 25 items on learning materials, lecturer's instruction, course schedule, learning difficulties, and four questions on administrative service. It was a 5-point Likert scale ranging from 5 to 1 in the order of strongly agree, agree, usually agree, disagree, and strongly disagree. The Cronbach's α-reliability of the six dimensions was higher than .8, indicating that each dimension had adequate reliability.

Learning Performance Questionnaire

The learning performance questionnaire evaluated students' performance during the activities. The questionnaire was developed by Lin et al. (2021) with a single dimension. Seven question items were used to determine learners' learning performance related to extended reality after class. These items aimed to give the researchers better indications of participants' learning performance concerning extended reality design and learning activities. The questionnaire was also designed as a 5-point Likert scale, with 1 representing "strongly disagree" and five representing "strongly agree"The items helped participants describe the current state of their learning performance.

Data Analysis

Analysis of variance was utilized in this study to determine the differences between the participants' learning responses and learning performance in the two groups. In addition, regression analysis was further applied to understand the relationship between learning response and performance. The pre-test of both groups was analyzed with an independent sample t-test, and the result reveals that both groups do not achieve significance in the pre-test (p = .751). During the data analysis, researchers used the SPSS program.

Research Results

An Analysis of Results Between the Control and Experimental Groups on Learning Response

According to the analysis of variance to find out the difference of extended reality integrated STEM in learning response, i.e., analysis and explanation of learning response, extended reality integrated STEM showed higher organization (3.87 > 3.14), clarification (3.98 > 3.46), repetition (4.05 > 3.51), supervision (4.12 > 3.49), concentration (4.18 > 3.62), effort (4.27 > 3.71), and teaching aid system (4.38 > 3.69) than the control group, as shown in Table 1. This finding is by an analysis of variance that explored the differences between extended reality-integrated STEM and the control group regarding learning response. As a result of this finding, H1 is supported.

Table 1
Difference Analysis of Extended Reality Integrated STEM in Learning Response

Variable	*F*	*p*	Scheffe post hoc
Organization	11.387	< .001	Extended reality integrated STEM (3.87) > control group (3.14)
Clarification	21.524	< .001	Extended reality integrated STEM (3.98) > control group (3.46)
Repetition	16.375	< .001	Extended reality integrated STEM (4.05) > control group (3.51)
Supervision	19.162	< .001	Extended reality integrated STEM (4.12) > control group (3.49)
Concentration	23.516	< .001	Extended reality integrated STEM (4.18) > control group (3.62)
Effort	25.483	< .001	Extended reality integrated STEM (4.27) > control group (3.71)
Teaching aid system	31.691	< .001	Extended reality integrated STEM (4.38) > control group (3.69)

$p < .05$

An Analysis of Results between the Control and Experimental Groups on Learning Performance According to the analysis of variance to determine the difference between extended reality integrated STEM in learning performance,

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i.e., analysis and explanation of learning performance, extended reality integrated STEM reveals higher learning performance (4.43>3.62) than the control group. This result demonstrates that the analysis and explanation of learning performance, extended reality integrated STEM reveals a higher learning performance than the control group, which provides support to the hypothesis that H2.

Table 2
Difference Analysis of Extended Reality Integrated STEM in Learning Performance

Variable	*F*	*p*	Scheffe post hoc
Learning performance	42.163	< .001	extended reality integrated STEM (4.43)> control group (3.62)

$p < .05$

Correlation Analysis of Learning Response and Learning Performance

To test H3, the analysis results, Table 3, reveal significant and positive effects of organization, clarification, repetition, supervision, concentration, effort, and teaching aid system (Beta = 0.206*; 0.213**; 0.224**; 0.233**; 0.239**; 0.245**; 0.261**) in learning response on learning performance that H3 is supported.

Table 3
Analysis of Learning Response to Learning Performance

Dependent variable → / Independent variable↓	Learning performance	
Learning response	***Beta***	***p***
Organization	0.206*	.016
Clarification	0.213**	.0001
Repetition	0.224**	.0001
Supervision	0.233**	.0001
Concentration	0.239**	.0001
Effort	0.245**	.0001
Teaching aid system	0.261**	.0001
F	67.839	
R2	0.472	
adjusted R2	0.463	

* $p < .05$. ** $p < .01$.

According to this result, the results presented in Table 3 reveal significant and favorable effects of organization, clarification, repetition, supervision, concentration, effort, and teaching aid system. This result suggests that Hypothesis 3 is supported.

Discussion

This research was to determine the effects of extended reality-integrated STEM education on student learning responses and performance. The main contribution of this study was to present the design and implementation

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of extended reality-integrated STEM education. Given that XR technologies used in this research are a new way of teaching STEM subjects to students, this way of teaching provided a mixture of augmented, virtual, and mixed reality as a novel approach to promote learning in STEM fields. From this point of view, XR represents a new approach to STEM education by enabling students to learn and understand subjects related to STEM and abstract concepts through problem-solving using the knowledge base in STEM fields. The XR was designed as a teaching method that provides interactive environments to facilitate meaningful learning. In this study, students used XR technologies to learn STEM-related topics.

Research results showed significant effects of extended reality-integrated STEM teaching on learning response. According to the results, extended reality integrated STEM teaching had statistically better results on learning performance than those in the control group. This result is because extended reality technology could support many teaching experiments to stimulate students' interest in teaching materials or teaching support systems. The possible reason for this result could be that the main advantage of extended reality-integrated STEM teaching is the ability of users to have real-time experiences that are not possible in the real world, create unique learning experiences, and increase student enthusiasm and engagement. This finding aligns with the study conducted by Di Natale et al. (2020), which explored the impact of AR or VR technology on learning outcomes during STEM activities.

The results showed that the XR technologies used in this study helped to improve students' learning perception and performance because it is important to point out that these technologies motivate students and make them maintain attention to the subject matter (Zatarain-Cabada et al., 2023). As indicated by Zatarain-Cabada et al. (2023), the significance of developing specific educational materials, including the arrangement of the learning space, the execution of effective instructional exercises, and the precision and excellence of instructional materials are important for increasing students' perceptions. These factors significantly impact the level of learning and performance achieved by learners. The research results showed remarkable effects of extended reality STEM on learning performance, consistent with the study of Xu and Wang (2022). The training environment for an immersive extended reality engineering lab provides students with experiences like those in a real lab. The advantage of an immersive extended reality learning environment is that it provides a simple and highly secure laboratory course, presents identical engineering experiment content in reality, and recreates the realization and interaction process. The research data and results showed that an immersive extended reality system could produce a positive learning effect, achievement, and specific practical experiences. The research results showed significant effects of learning response on learning performance, consistent with the research of Jiang et al. (2022). Integrating new technologies and visualization tools into artificial intelligence teaching materials could effectively promote students' participation in artificial intelligence classes, increase students' willingness to engage with artificial intelligence, stimulate students' feedback for better learning responses, and promote students' learning performance in artificial intelligence. In a similar research study, Zatarain-Cabada et al. (2023) evaluated students' perceptions of web-based XR technologies for teaching by using a learning application that combines virtual reality and augmented reality environments to provide students with the necessary didactic materials to learn physics. According to their findings, both virtual and augmented reality significantly affected motivation. However, the impact of activities in AR mode on student motivation to learn was greater than in VR mode. With this respect, the results of Zatarain-Cabada et al. (2023) are similar to those of the present study. The earlier studies and the present study suggested that well-designed learning tools, including extended reality, can greatly impact a learner's performance. Factors such as the quality, accessibility, and clarity of instructional materials are crucial in achieving this goal (Zatarain-Cabada et al., 2023). The results are also similar to those of Ibanez et al. (2020), who reported significant effects of augmented reality-based learning environments using the web-based application on learning outcomes, and the augmented reality learning environment was more effective for learning than the web-based learning environment. The results obtained are also very similar to the findings of Liou et al. (2017), who revealed that augmented and virtual reality had significant effects on learning performance. The results showed that the XR technologies demonstrated a positive and significant effect of learning response on learning performance. XR technologies in this study created a new and effective way for students to learn in STEM education. It gave them a unique learning environment and instructional strategy that improved their performance. Researchers have reported that the implementation and use of augmented and virtual reality technologies enabled students to focus on STEM disciplines and topics and helped them better understand the concepts presented in STEM activities (Akçayır et al., 2016; Ibanez et al., 2016; Liou et al., 2017).

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Conclusions and Implications

STEM can be applied to real life with extended reality technologies that push students to learn knowledge and skills. STEM presents interdisciplinary interests, experiences, situations, collaboration, design, implementation, and technology. Regarding student learning, it is important to consider their subject matter knowledge and life experience and focus on their needs. In this study, researchers applied an extended reality-integrated STEM experimental activity to the students in the experimental group. At the same time, for the students in the control group, the teaching was carried out with the help of computers, course materials, and teaching aids. The research results showed that the experimental group students who applied the extended reality-integrated STEM achieved better learning results than those in the control group who used teaching materials. The post-test data analysis showed that the experimental group students outperformed the control group many times. The students in the experimental group outperformed the learning performance of the control group STEM. From the data analysis, it can be inferred that the students in the experimental group could apply the knowledge from the STEM curriculum and reflect the learning outcomes, so they showed better learning performance than the students in the control group. The results showed that extended reality technologies could enhance participants' learning responses and performance.

Recommendations

It is suggested in the study that extended reality integrated STEM curriculum could cooperate with various areas to design interdisciplinary curricula, add tasks and challenges with definite goals for students' learning, as well as deepen the learned knowledge and apply the learned through cross-field collaboration and hands-on to achieve better learning effect. Lecturers would encounter resource problems when proceeding extended reality-integrated STEM curriculum, which requires more resources like field, equipment, and classroom facilities. A university should be able to provide resources to develop the curriculum. In this case, the universities should support STEM teaching for complete and adequate curriculum development. Moreover, team support and understanding of various teaching methods are required to develop such curricula to achieve the objective and effectiveness more easily.

It is not easy to search for topics for an extended reality integrated STEM curriculum, the curriculum design would take much time, and the preparation is time-consuming, including the confirmation of course topic, activity process, and material purchase and preparation. It is therefore suggested that lecturers should well apply teamwork, group the curriculum team, and collaboratively prepare and precede the curriculum. Although it would take much time, the students' reflection shows the curriculum's benefit, revealing its positive effect.

Limitations

This study has limitations that should be noted. Firstly, the results cannot be generalized to a wider population due to the limited number of participants and the specific intervention used. This issue is common in educational research. Secondly, the study only looked at short-term retention of extended reality teaching. A longer-term evaluation would have provided more insights into the effectiveness of the STEM activities. Additionally, the lecturer who taught the extended reality course was the same person who taught the control group. The lecturer's educational background and their use of extended reality in STEM teaching can impact the outcomes. Thirdly, the study had a limited number of participants, and a larger study with more participants is needed to draw more conclusive results. It is important to mention that all participants volunteered to take part. Finally, the study found that extended reality STEM activities were more effective than teaching in a control group, such as textbooks and digital films. However, these activities' efficacy has some limitations, as discussed above.

Declaration of Interest

The authors declare no competing interest.

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