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In electronic environment of bridging green education and performance: The transformative role of augmented reality technology in sustainable environmental learning

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Abstract

Investigating the role of augmented reality technology (ART) in mediating the relationship between students' academic performance and sustainable environmental knowledge practices is a key objective that, in addition to the effect of ART on self-perceived academic performance, is also examined. The purpose of this research was to bridge the electronic environment of green education and performance: the transformative role of augmented reality technology in sustainable environmental learning. The research method was applied-quantitative, with the statistical population consisting of students from three universities, of whom 60 were randomly selected for the research sample. The research tool was a researcher-made questionnaire that was completed using Survey Monkey, an online platform for preparing and responding to questionnaires. To analyze the collected data, descriptive statistics were used to prepare tables and graphs, and for inferential statistics, the regression statistical method was used to examine the relationship between variables, with SPSS software employed for data analysis. The results of the research showed that sustainable environmental knowledge has a negligible effect on students' self-perceived academic performance. The study indicated that AR technologies introduced in learning enhanced the relationship between sustainable environmental knowledge and self-perceived academic performance by significantly improving critical thinking among students, as well as enhancing attention, mediating, and improving memory and comprehension. Meanwhile, a crucial recommendation for future research is that qualitative data through interviews should be collected to identify specific applications that can be incorporated into AR to enhance students' learning experiences, and that incorporating augmented reality technologies in higher education institutions can increase students' attention and improve their self-efficacy.

Keywords: Academic, Performance, Augmented Reality, Green Education, Sustainable, Technology, ART.

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1. Introduction

1.1. Background

Green education is a pedagogical approach that focuses on teaching ecological concepts, sustainable practices, and environmental issues to students [1]. Essentially, green education is linked to high environmental knowledge and helps to create awareness of sustainability and environmental conservation among students [2]. Additionally, students can understand the interconnection between various fields and the environment. Green education also enables students to start learning about the environment early and make informed decisions about sustainability practices throughout their lives. UNESCO has been at the forefront of promoting green education in response to the dramatic and urgent climate [3] change challenges facing the planet. In this regard, governments, facilitated by education departments, have allocated resources to implement environmentally focused education in schools, utilizing technological innovations such as augmented reality. Augmented reality technology (ART) uses digital perceptual information to create interactive, real-life experiences. Essentially, AR is anchored on simulation principles and uses computer-generated content to mimic real-world scenarios. [4, 5] stated in a study that both students and teachers reported positive effects of AR methods on improving understanding of scientific topics, providing a visual introduction to the subject, and aiding classroom interaction during class hours. AR interactive features and 3D visualization create an immersive virtual environment that improves user experience and has led to applications in various sectors, including healthcare, transport, manufacturing, and gaming. In education, as highlighted by Yılmaz and Göktaş, AR technology is applied to enhance students' learning experiences [6] and [7].

Chen [8] reported that in the validated model, students' science learning self-efficacy affects their environmental sustainability behaviors, but only through the role of environmental attitudes. However, the structure of environmental attitudes plays a mediating role in the model. ART application in education makes learning more interesting, keeps students engaged, promotes collaboration, and fosters curiosity among students Yılmaz and Göktaş [6] and Avila-Garzon, et al. [7]. Küçük, et al. [9] stated in a study that sensory experience and real-time interaction with the environment may provide learning satisfaction and enable students to structure their knowledge to complete learning tasks. Due to this, AR is gaining prominence in the learning environment, with its integration inspired by the latest introduction of advanced technological teaching solutions in the education sector. In history education, AR assists students to appreciate ancient designs, creatures, and cultures. In health education, AR is suitable for anatomy studies. Other areas of ART application include biology, physics, chemistry, geometry, astronomy, and engineering education Avila-Garzon, et al. [7]. Ebili [10] also stated that AR helps to reduce foreign cognitive load and increase German cognitive load. On the other hand, the impact of AR systems, which are difficult and complex in terms of instructional design, on cognitive load was revealed. Some instructional methods and design principles that can be effective as solutions were presented. In addition, the effects of motivational stimuli on preventing or expanding students' cognitive capacity were described. Finally, the potential and limitations of AR interaction interfaces on cognitive load were explained. The results of this research provide important clues for AR developers and instructional designers in the field of reducing cognitive load and eliminating working memory limitations. In that respect, ART in education is used in science and art learning. This article's area of interest is the application of ART in environmental science education. Specifically, this study addresses how AR influences knowledge and motivation for green practices and the ultimate effect on learners' academic performance. Avila-Garzon, et al. [7] stated that the results also indicate that there is a growing interest in exploring the use of AR in higher education settings, as previously mentioned by López et al. This result also confirms the previous findings of Avila-Garzon, et al. [11] who noted that higher education and primary education are the two educational levels for which more AR research has been conducted. One topic that did not appear among the popular topics is the development of authoring tools that enable teachers to create content for augmented reality learning experiences or modify existing content to add new capabilities. This topic has been frequently reported in the literature, another issue that appears as a significant concern is that public schools should provide the technologies needed to implement augmented reality learning experiences, so that all students can have a similar experience, given that some students may not have access to certain technologies. Buchner, et al. [12] stated in a study that compared to other technologies, AR appears to be less cognitively demanding and also leads to higher performance. However, these results are based on media comparison studies that have been criticized for years. Spatial AR is better compared to through-view AR. However, the latter can be improved with visual cues and the addition of learning activities, such as value-added studies. The increased use of technology in homes and businesses is associated with a high environmental impact [5, 13].The adverse effects of technology include increased energy consumption and electronic waste. ART holds a promising position for spearheading the promotion of ecological awareness. Bekaroo, et al. [14] noted that ART facilitates environmental education through self-learning, whereby the real-world objects are presented in a virtual surrounding that allows real-time engagement [14]. ART imprints the 3-D view of the environment, allowing individuals to have a real-time view of the world and understand the factors affecting the environment. Consequently, ART systems are widely associated with positive environmental education outcomes [8].

Chen also showed that students exposed to AR digital picture books expressed a more robust understanding of the natural environment [8]. Aisyah [15] stated in a study that this research is expected to be considered in further developing the application of sustainable learning with the POE model, as this learning is new in the development of other innovative learning methods. Another new point found in the materials obtained in this study is that continuous learning using the POE model is very suitable for teaching students' critical thinking skills. Learners acquired positive environmental attitudes and self-efficacy for participation in green consumption. Meanwhile, Liang et al. highlighted that ART positively contributed to sustainable physical education outcomes [16]. Hence, ART encourages positive learning behaviors and attitudes toward the environment. Despite the positive remarks about ART in green education, studies have revealed some negative implications. Czok, et al. [17] indicated that using ART exposed students to large amounts of learning content simultaneously, leading to a high cognitive load [17].

Cognitive load describes the amount of data that the working memory process at a time. In that regard, high cognitive load means overloading the student's memory with information, resulting in poor long-term storage [18]. As a result, learners using ART utilize most of their working memory space, leading to fatigue, stress, frustration, and impaired learning. Similar views were shared by İbili [18] who noted that ART increased germane and intrinsic cognitive loads to overwhelming levels that contributed to memory overload [12, 18]. Nevertheless, studies show that AR reduces extraneous cognitive load, improving concentration in processing information for learning purposes Buchner, et al. [12]. Li and Hsu [19] also reported in a study that the proposed approach also effectively increased students' self-efficacy and reduced their cognitive load. Students with a reflective learning style had a higher cognitive load than students with an active learning style when using the e-book learning approach. No difference in learning motivation was observed between the experimental and control groups. Overall, Makeup AR is suitable for makeup design certificate courses in vocational high schools and can increase learning effectiveness, improve students' self-efficacy, and reduce cognitive load. This study suggests that implementing AR technology in certificate courses can be beneficial for learning outcomes. Specifically, extraneous cognitive load refers to the mental content that do not contribute to learning, whereas intrinsic cognitive load refers to the difficulty in processing information. The real application of ART in learning has shown that it helps to improve the reliability and accuracy of educational materials Aggarwal [1]. Küçük, et al. [9] also reported that ART use among medical students led to better academic outcomes and reduced cognitive load [9]. In particular, ART improves the visualization of abstract information, thereby enhancing information processing and lowering the cognitive load. Inconsistencies in the literature show that ART's effect on educational performance is not fully understood. Moreover, the learning outcomes of ART in sustainability studies have not been explored [20]. The knowledge regarding the impact of ART on students' green education perception and performance is limited. Further, the literature body has a shortage of studies linking the advantages of sustainable environmental knowledge and academic performance. This research seeks to fill the literature gap by considering ART as a mediating variable when striving to improve academic performance in green education. In this context, the mediating variable describes the path through which two separate variables are connected. Therefore, ART will define the process through which sustainable green education practices and academic performance are related. Essentially, the main focus is how ART application in sustainable green education influences the cognitive outcomes of learners and how the resultant behavior relates to the overall academic conduct. In this respect, ART is a mediating factor between environmental knowledge and academic performance parameters. As such, the study tests the indirect contribution of green motivation to learning outcomes. The current study's main aim is to investigate ART's mediating role in the link between sustainable green education and self-perceived academic achievement of students. Specific objectives include: To examine sustainable green education's effect on ART usage. To investigate the impact of ART use in green learning on self-perceived academic performance. To examine the effect of sustainable green education on self-perceived academic performance.

2. Research Method

2.1. Research Philosophy and Design

The research method applied was quantitative, with the statistical population consisting of students from three universities. From this population, 60 students were randomly selected for the research sample. The research instrument was a researcher-made questionnaire, which was completed using Survey Monkey, an online platform for preparing and responding to questionnaires. Participants took part in the online survey. The present study is based on the philosophy of positivism, which posits that there are universal laws governing human behavior. Therefore, positivists emphasize that objective reality can be understood by analyzing measurable data and generalizing the results to the target population [20].

For this study, the philosophy of positivism was considered appropriate because it ensured that the relationship between sustainable environmental knowledge, AR, and academic performance could be understood to recommend best teaching practices. In addition, this study used a descriptive design, which requires reliance on quantitative data to describe a specific phenomenon [21]. The descriptive design helped answer the "what" questions about the link between sustainable environmental knowledge and academic performance. This design is considered appropriate because it ensures that the hypothesis can be tested and a clear conclusion can be drawn to answer the research question. In this study, a quantitative approach was considered relevant because it helps to find patterns in the data and test the causal relationship between AR technology, sustainable environmental knowledge, and self-perceived academic performance. The quantitative method was employed by conducting surveys, which enabled a large number of participants to be involved and improved the accuracy and reliability of the results. The present study also relies on a deductive approach, which involves testing hypotheses to expand the existing knowledge about a phenomenon. The deductive approach was considered appropriate for this study because it helped to generate definitive findings that ensured the confirmation or rejection of the hypothesis. The conceptual framework of this study is shown in Figure 1, which illustrates the independent variable, mediating variable, and dependent variable. To analyze the collected data, descriptive statistics were used to prepare tables and graphs, and for inferential statistics, the regression statistical method was used to examine the relationship between variables, with SPSS software employed to analyze the data.

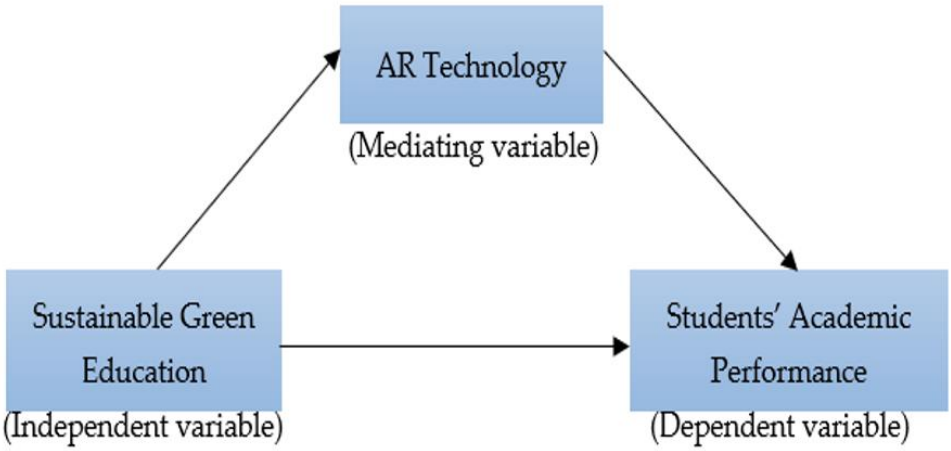

Figure 1.
Research conceptual framework.

2.2. Population and Sampling

The population targeted in this study did not involve all students but instead, only those who had at least one-year experience in using AR technology. In this case, the emphasis was that the students should have used similar AR systems provided in school for learning at least one subject over a prolonged period. The AR technology considered in this study involved project-based interactive system where students are exposed to virtual 3D images of concepts learned in class. Teachers were not considered in the survey conducted because of difficulty in accessing many teachers who have experience in using AR in teaching practice. A convenience sampling technique was used to select individuals to participate in the study. In convenience sampling, the researcher selects respondents who are readily available for the investigation [22, 23]. Notably, the convenience sampling technique applies random concepts of approaching and identifying qualified participants. This sampling technique eliminates selection bias by presenting equal opportunities for all potential participants. Convenience sampling provides a crucial advantage in enabling the selection of many participants in quantitative surveys [24]. Additionally, the method is cost-efficient and simple to implement, especially in designated premises such as schools and companies. In this study, the convenience sampling technique was applied by seeking the help of friends and colleagues to recruit college students who had previously used AR in learning. The sampling process was conducted over two weeks, during which sampled students were initially requested to help recruit colleagues who had similar knowledge [25]. Inclusion criteria were considered in the sampling process. Firstly, the selected participants demonstrated knowledge and skills in AR technology for educational purposes. Therefore, individuals lacking experience on using AR technologies in education were not considered for the study. The rationale for the criterion was to ensure that participants sampled had relevant knowledge on the topic. Secondly, participants needed at least one year of experience with AR technology in the education system. The rationale for the time aspect was to ensure that only participants with a thorough understanding of the researched topic were considered for the study. Thirdly, the participants were chosen based on their previous completion of a sustainability course. In that respect, the study only considered students who employed AR reality in gaining environmental knowledge were considered. Eventually, 60 participants, involving students, were selected from three universities within the US to participate in the surveys. An equal number of male and female participants was used to improve generalization of findings based on gender.

2.3. Data Collection and Analysis

The first step in data collection was the preparation of survey questionnaires. The process was completed using Survey Monkey, an online platform for preparing and answering questionnaires. Notably, survey questionnaires adopt a closed-ended format with a multiple-choice answer structure, allowing participants to express specific opinions (Appendix). Informed consent from participants was obtained before engaging them in the data collection process. A crucial strength of online surveys is that they enhance flexibility for participants and researchers since there is no need to travel to meet and share documents. Online surveys also facilitate data organization since the responses are entered digitally and organized automatically using embedded software. Therefore, online surveys save resources and promote efficient data collection and analysis. Each survey session was designed to take about 20 minutes. The researchers ensured that the surveys were direct and precise so that participants could understand and provide specific responses. Participants were allowed to skip questions they did not know to maintain the integrity of the research results. However, for this study, all questions were answered, and there were no issues of missing data [26].

Data from the survey were analyzed using statistical analysis techniques. A crucial benefit of statistical analysis is enabling the identification of complex patterns in a large dataset [27]. The statistical analysis undertaken involved descriptive and inferential analysis. Descriptive analysis helped to identify trends in the dataset, while inferential analysis was used to determine the relationship between the variables. Statistical analysis also improves the generalization of results to a specific population [28]. For this research, regression analysis was employed to understand the relationship between academic performance, augmented reality use in learning, and sustainable environmental knowledge. Data analysis was conducted in SPSS to enhance the quality of output in graphics. The findings were summarized in tables and graphs.

3. Results and Discussion

3.1. Results

3.1.1. Descriptive statistics

The results of the impact of AR on self-perceived academic performance are shown in Figure 2.

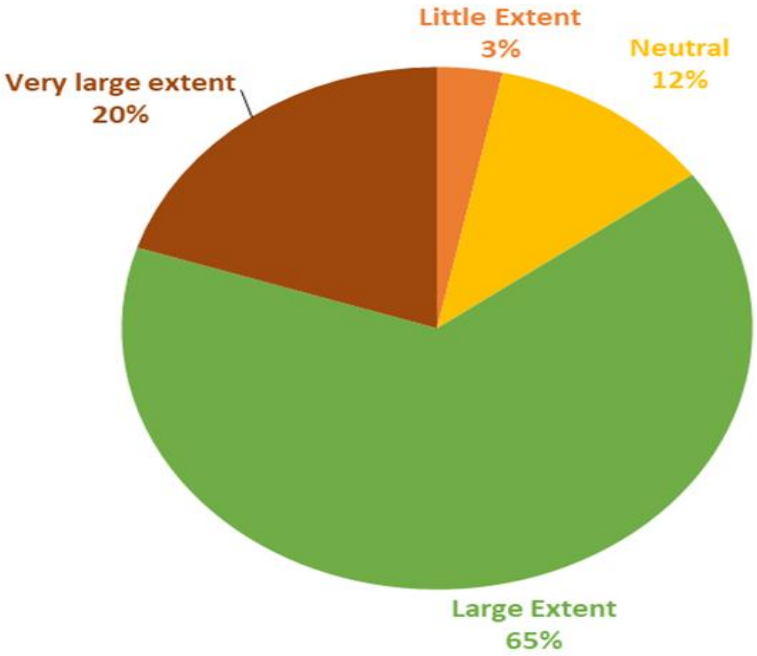

Figure 2.
Self-perceived academic performance improvement after using AR.

According to Figure 2, AR use in education improved perceived students' academic performance, suggesting that AR produces positive results in the students' learning experience. Most participants (85%) agreed that using AR improved the perceived academic performance to a large or very large extent. Notably, only a small segment of the participants (15%) felt that AR had little or no positive influence on their perceived academic performance. The implication is that AR enhances learners' cognitive capabilities, leading to higher comprehension, memory, and information retention. As such, many students have benefited from this technological initiative.

The trends regarding the influences of environmental knowledge on education outcomes are shown in Figure 3. According to Figure 3, sustainable environmental knowledge was assessed based on five variables: environmental consciousness, creativity, healthy behavior, critical thinking, and community participation. Expressly, 95% of the participants agreed that sustainable environmental knowledge increased the environmental consciousness among learners. None of the participants disagreed with the contribution of sustainable environmental knowledge to environmental consciousness, implying that the learning model effectively delivers its mandate. Meanwhile, most respondents (90%) agreed that sustainable environmental knowledge enhanced creativity among learners. The creativity aspect showed that sustainable environmental knowledge is tailored towards improving the thinking and innovative capabilities of learners.

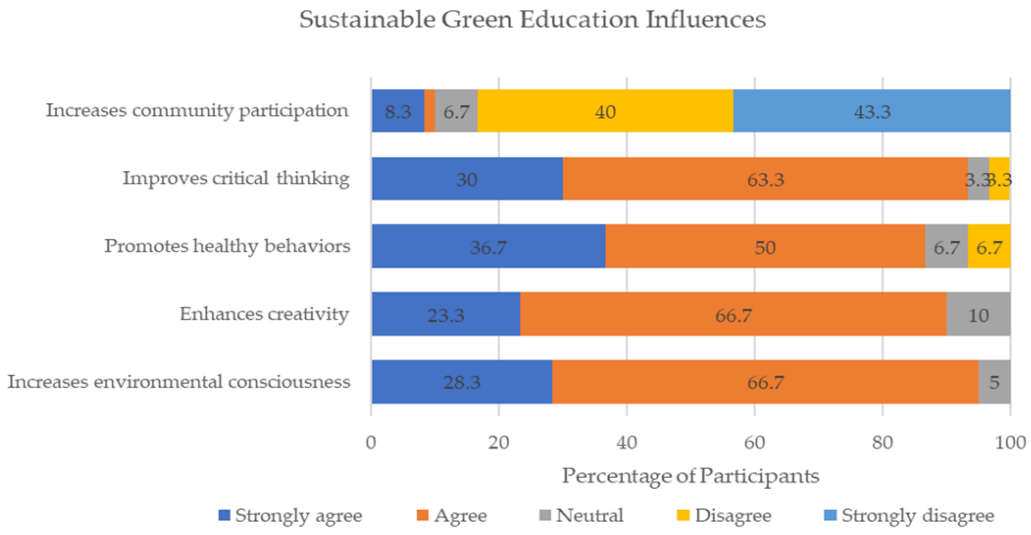

Figure 3.
Sustainable environmental knowledge influences.

Additionally, 93.33% of the participants agreed that sustainable environmental knowledge improved critical thinking, suggesting higher levels of conceptualizing variables to make informed decisions. In this regard, the observation implied that sustainable environmental knowledge expands the psychological sphere of students in terms of reasoning, comparison, and contrast. According to the results, a few participants disagreed with the critical thinking idea, showing that some learners respond negatively to sustainable environmental knowledge. Besides, most respondents (86.67%) agreed that sustainable environmental knowledge promoted healthy behavior, including a nutritious diet, physical activity, and caring for the environment. The finding implies that environmental conservation is proportional to clean activities, which improve health outcomes. As such, learners are reportedly healthier after taking environmental knowledge lessons. However, 83.33% of the participants disagreed that sustainable environmental knowledge increased community participation. The finding reveals that academic knowledge of environmental sustainability is not associated with the willingness of students to engage in practical community environmental protection programs. In that regard, sustainable environmental knowledge mostly influences students' behavior in the academic context.

The trends concerning AR application in learning are shown in Figure 4. In Figure 4 the overall observation is that most participants concurred with the various elements of AR application in a learning context. Specifically, most respondents (93.33%) agreed that AR materials enhanced their attentiveness, revealing the substantial contribution of AR learning materials to mental focus and concentration. The implication is that AR materials help individuals develop an interest in lessons because of the visual and interactive features.

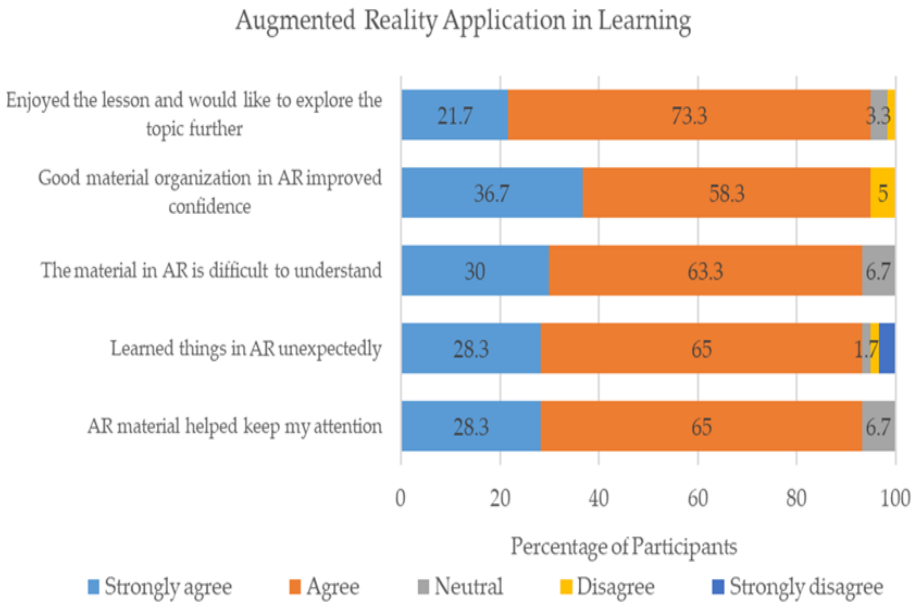

Figure 4.
Augmented reality application in learning.

Most participants (93.33%) agreed that AR materials helped them with learning unexpected things, unveiling the depth of AR in educative content. The finding implies that AR presents detailed learning materials that expose learners to fresh content, leading to increased knowledge of the respective subjects and disciplines. Additionally, 95% of the participants indicated that they enjoyed the lessons conducted using AR and would like to explore the topics further. The finding implies that AR materials impart the desire to learn in students. The new revelations noticed in AR-aided lessons equip the students to discover items and develop an extended understanding of the subjects. Furthermore, 95% of the participants confirmed that good organization of materials in AR improves learners' confidence. The finding implies that AR application in learning simplifies lesson plans through the computer-aided chronology of presenting content. The observations show that most students are thrilled to have lessons covered using AR materials. However, the participants overwhelmingly agreed that AR materials for learning are difficult to understand. The point was supported by most participants (93.3%), indicating the sophisticated nature of AR applications in education. The finding implies that learners must put in more effort to navigate AR-aided lessons.

3.1.2. Effect of Augmented Reality on Academic Performance

The effect of AR on self-perceived academic performance was measured by performing a regression analysis. The result is in Table 1. Based on the regression model in Table 1, the R-squared value is 0.188, suggesting that the influence of AR has an 18.8% impact on self-perceived academic performance. The impact is statistically significant, as indicated by $p = 0.041$. The finding implies that AR materials in learning produce a substantial effect on specific learning outcomes and boosts academic performance. From the results, the contribution of AR materials to attention retention has a positive and significant relationship with academic performance ($B = 0.337$, $p = 0.078$). The finding implies that academic performance relies heavily

on the quality of student attentiveness to details. Therefore, AR mediates academic performance through the lattice of supporting better concentration.

Table 1.
Effect of augmented reality on self-perceived academic performance.

Variable	Coefficient (B)	Std. error	P-value
Constant	1.221	0.890	0.175
AR material helped keep my attention.	0.337	0.187	0.078*
Learned things in AR unexpectedly.	0.041	0.165	0.804
The material in AR is difficult to understand.	0.159	0.158	0.317
Good material organization in AR improved my confidence.	0.028	0.176	0.872
I enjoyed the lesson and would like to explore the topic further.	0.098	0.190	0.606
Model R-square value	18.8%		
Model P-Value	0.041		

Note: Dependent Variable: Self-perceived academic performance (Figure 1 results) * indicates sig. at p < .1 level.

The remaining indicators of academic performance (learning unexpected things, difficulty understanding AR materials, confidence, and enjoyment of lessons) all had a positive but insignificant relationship with academic performance. The positive coefficient of difficulty in understanding AR materials was unexpected but was attributed to students being encouraged to seek assistance with AR use, which eventually improves their learning. The lack of significance in most predictors shows that AR materials must be complemented by conventional teaching methods for improved academic performance. Overall, AR positively and significantly influences academic performance.

3.1.3. Effect of Sustainable Environmental Knowledge on AR Use

The effects of sustainable environmental knowledge on AR use were determined by performing a regression analysis. The finding is in Table 2.

Table 2.
Effect of sustainable environmental knowledge on AR use.

Variable	Coefficient (B)	Std. error	P-value
Constant	2.838	0.743	0.000
Increases environmental consciousness	-0.036	0.132	0.788
Enhances creativity	-0.001	0.134	0.992
Promotes healthy behaviour	0.097	0.092	0.297
Improves critical thinking	0.302	0.116	0.012*
Increases community participation	-0.072	0.061	0.239
Model R-square value	18.4%		
Model P-Value	0.046		

Note: Dependent Variable: Self-perceived academic performance (Figure 1 results) * indicates sig. at p < .1 level.

From Table 2, the R-squared value is 0.184, meaning sustainable environmental knowledge has a collective impact of 18.4% on AR use in learning. The regression model is positive and statistically significant, as shown by p = 0.046. The finding implies that sustainable environmental knowledge is more effective when AR materials are considered in learning. In other words, sustainable environmental knowledge also relies on AR materials for detailed illustrations for better understanding. Improving critical thinking has a positive and significant relationship with the independent variable (B = 0.302, p = 0.012). The finding implies that learners' attention is crucial in sustainable green environment learning and reveals the need for AR materials. The intervention helps students to focus on environmental elements with ease. Apart from improving critical thinking, the remaining variables depicted a negative relationship with the dependent variable. The implication is that factors of ecological consciousness, creativity, and community participation have little to do with sustainable environmental knowledge. Therefore, a balance must be determined among the predictor variables for a considerable effect of sustainable environmental knowledge on AR use.

3.1.4. Effect of Sustainable Environmental Knowledge on Self-Perceived Academic Performance

The effect of sustainable environmental knowledge on self-perceived academic performance was also addressed through regression analysis. The result is indicated in Table 3.

Table 3.
Sustainable environmental effect on self-perceived academic performance.

Variable	Coefficient (B)	Std. error	P-value
Constant	2.807	0.961	0.005
Increases environmental consciousness	-0.082	0.171	0.633
Enhances creativity	0.159	0.173	0.364
Promotes healthy behavior	0.131	0.119	0.277
Improves critical thinking	0.100	0.150	0.507
Increases community participation	-0.035	0.079	0.661
Model R-square value	8.2%		
Model P-Value	0.451		

Note: [1] Dependent Variable: Self-perceived academic performance (Figure 1 results) * indicates sig. at p < .1 level.

According to the results from Table 3, the R-squared value is 0.082, indicating that sustainable environmental knowledge has an overall 8.2% effect on academic performance. Further, the effect is insignificant (p > 0.1), revealing that sustainable environmental knowledge has little influence on academic performance parameters among students. All the sustainable environmental knowledge variables have an insignificant relationship with academic performance. Nonetheless, creativity, healthy behavior, and critical thinking are positively related to academic performance. The finding implies that most students and teachers have isolated the benefits of sustainable environmental knowledge to environmental conservation, with limited extension to general classwork. Additionally, the finding shows that students cannot fully transfer the benefits of environmental knowledge to academic work directly. The results also show that increased environmental awareness and community participation have a negative relationship with academic performance. The finding implies that these two components of sustainable environmental knowledge deprive learners of the opportunity to focus on academic materials. In that respect, environmental knowledge has both positive and negative effects on learners' academic performance with no equilibrium point. Therefore, students are affected by the influence acquired due to the nature of the environmental knowledge received.

3.1.5. Mediating Role of Augmented Reality Use Between Education and Academic Performance

Mediation analysis was conducted using process procedure to determine the association between sustainable environmental knowledge, AR technology, and self-perceived academic performance. Mediating variable explains the process through which two other variables are connected. An example of mediation in healthcare is that in the relationship between physical therapy and mobility, muscle development is a mediator. This means that among patients given physical therapy, only those who demonstrate increased muscle development are likely to show a significant increase in mobility. For this study, the results are shown in Figure 5.

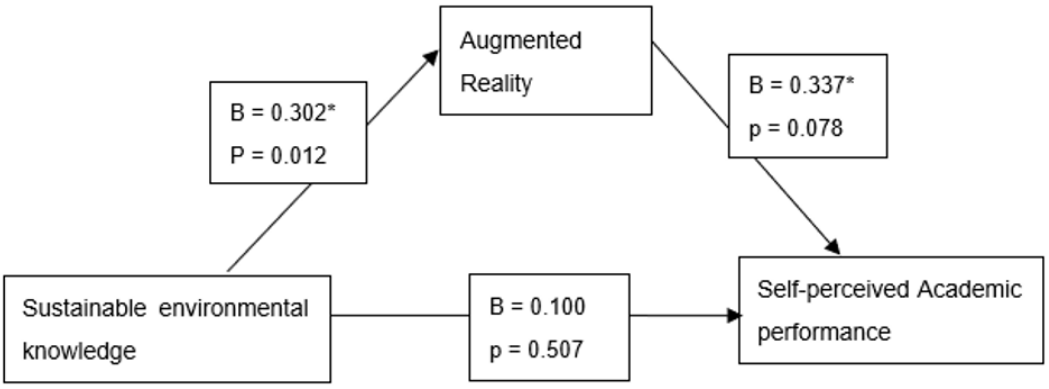

Figure 5.
Mediating role of AR * significance at p < .1 level (2-tailed).

A crucial observation from Figure 4 is that sustainable environmental knowledge does not have a significant association with self-perceived academic performance (B = 0.100, p = 0.507), implying that these two variables lack a direct connection. Meanwhile, the results show a significant association between sustainable environmental knowledge and AR (B = 0.302, p = 0.012), indicating a direct connection. Further, the results show a significant association between AR and academic performance (B = 0.337, p = 0.078). This conclusion is based on the p-value of 0.078, which is less than 0.1 and signals a significant relationship between AR and academic performance. The trend indicates that although there is no direct connection between sustainable environmental knowledge and academic performance, an indirect influence can be achieved by using AR materials in learning. The result confirmed the alternative hypothesis H1A developed at the start of this research, indicating that AR is crucial in promoting the link between academic outcomes and sustainable environmental knowledge. Academic contributions to sustainable environmental knowledge can be transmitted effectively through AR materials. As such, the results show that AR technology in learning has a mediating role in improving the relationship between sustainable environmental knowledge and students' academic performance.

3.2. Discussion

The first result was that the R2 values are quite low for Table 1. Frost indicates that even low R2 values can lead to significant results. However, Frost also highlights that low R2 values pose errors and limitations with interpretation. The issue of low R2 value was also identified in Table 2 and especially in Table 3, where R2 is only 8.2%, suggesting that the model explains only 8.2% of self-efficacy. Moreover, the findings showed that sustainable environmental knowledge positively affects AR technology usage. The components of sustainable environmental knowledge linked to AR usage included enhancing creativity, increasing environmental consciousness, promoting healthy behaviors, and improving critical thinking. In that respect, the finding implies that AR can advance the goals of sustainable environmental knowledge. The result aligns with Bekaroo, et al. [14]; Herpich, et al. [29]; İbili [18]; Paredes-Velasco, et al. [28] and Hoang and Kato [30] views, revealing that AR facilitates education about the green consumption of electronic appliances. The finding resembles that of Lee and Hsu [31]; Aggarwal [1]; Buchner, et al. [12] and Bloomfield and Fisher [21] who revealed that AR application in education enhanced students' self-efficacy for learning diverse sustainability aspects [29, 31]. Meanwhile, regression findings indicated that only the effect of improving critical thinking is positively and significantly associated with the AR variable of keeping attention (B = 0.302, p = 0.012). The implication is that sustainable environmental knowledge mainly influences the use of AR technology by enhancing critical thinking. The finding is consistent with that of Straková and Cimermanová [32]; Liang, et al. [16]; Nayak and Narayan [33] and Casula, et al. [25] who pinpointed that critical thinking skills positively impact learner's capacity to appreciate and embrace sustainability education [24]. The results also resonated with the submission of Ekamilasari [34] who stated that critical thinking mediates sustainability and sustainable development in the teaching of students [13]. Hence, the current study suggests that sustainable environmental knowledge and AR technology use are intertwined. The results also demonstrated that AR materials in learning affect self-efficacy in four critical ways. Firstly, AR materials enhance the attention of learners, pointing to the role of technology in generating students' interest in learning. The observation was overwhelmingly supported by 93.33% of the participants, implying that many learners have reported improved concentration when using AR materials. Moreover, the regression analysis revealed that the factor is significant in influencing self-efficacy. The finding is consistent with that of Herpich, et al. [29] who showed that mobile AR improved student engagement, leading to longer attention outcomes than conventional teaching methods [6, 22, 32]. However, the result contrasted the views of Czok, et al. [17] who highlighted that using AR can expose students to a large amount of learning content in a short period, which causes cognitive overload [27, 28]. As such, instead of improving performance, students can exhibit increased frustration, stress, and fatigue. Based on the findings and literature, it is noted that while AR has the potential to increase self-efficacy, it should be applied carefully where it is used to complement theoretical concepts in class to achieve positive learning outcomes. Based on the findings and literature, augmented reality (AR) shows the potential to enhance self-efficacy when carefully integrated to complement theoretical concepts in classroom settings, thereby achieving positive learning outcomes. Secondly, the survey findings showed that AR materials led to lesson enjoyment and improved confidence among learners. The finding resembles that of Paredes-Velasco et al., showing that applying AR and visualizations produced positive emotions in students characterized by activity stimulation, enjoyment, and declined boredom [27]. However, contrasting views were noted by Khan, et al. [35] showing that AR can be of less relevance to students if not designed properly to complement lessons taught in class [22] To optimize the efficiency of the educational process, AR should be aligned with concepts taught in class to ensure increased student performance. In addition, the results indicated that sustainable environmental knowledge does not affect self-efficacy. In particular, the regression analysis showed an insignificant influence of 8.2%, suggesting that sustainable environmental knowledge does not directly affect students' self-perceived academic performance. The finding contrasted submissions by Kweon [36] showing that schools with environmental sustainability programs registered higher scores in reading and mathematics tests than those lacking the programs [3]. Moreover, in the current study, all environmental knowledge variables depicted an insignificant relationship with self-efficacy. The implication is that sustainable environmental knowledge only contributes to environmental protection and does not improve the academic aspects of learners. The result is aligned with the views of Olsson, et al. [27] indicating that green schools do not affect students' sustainability consciousness [22]. The findings of the current study also showed that increased environmental consciousness negatively affected self-efficacy. Therefore, a weak association exists between sustainable environmental knowledge and self-efficacy. Improving critical thinking and enhancing creativity exhibited a positive but insignificant relationship with self-efficacy. The finding implies that sustainable environmental knowledge has specific important attributes for promoting academic excellence, but their impacts are underexploited. The finding echoes that of Hoang and Kato, who noted increased levels of environmental knowledge in 96% of students after environmental education activities, confirming that environmental knowledge outcomes are mainly ecological-oriented [22, 27, 28, 33]. Thus, learners exposed to sustainable environmental knowledge will perform well in environmental management activities but lack ways of linking the acquired expertise to the academic sphere. Finally, the current findings revealed that while sustainable green learning does not directly affect self-efficacy, including AR as a mediating variable ensures an indirect significant relationship between the two variables [3]. Specifically, the result showed that when AR is used for sustainable environmental knowledge, students exhibit higher critical thinking and elevated levels of attention, which eventually translates to better knowledge retention and improved self-efficacy. The finding confirmed the alternative hypothesis H1A, showing that AR's mediating role significantly promotes the relationship between sustainable environmental knowledge and self-perceived academic performance. The finding aligns with the view of Chen, who pinpointed that AR led to positive attitudes towards learning, which culminates in enhanced performance [32]. However, contrasting views were presented by İbili, showing that when AR is not used appropriately, it can lead to students experiencing cognitive and memory overload that culminate in declined academic performance [28]. To optimize AR's mediating role in enhancing the relationship between self-efficacy and environmental knowledge, carefully considering the information included in AR and its relevance

to students' learning programs is crucial to ensuring high levels of attention and critical thinking. The primary research aim was to investigate ART's role in mediating the link between sustainable environmental knowledge and self-perceived academic performance. The first objective involved examining the effect of sustainable environmental knowledge on ART use. The second objective entailed exploring the impact of ART on self-perceived academic performance, while the third objective investigated the effect of sustainable environmental knowledge on self-perceived academic performance. The research methodology involved using the survey to gather data from 60 participants. After analysis, all three objectives were achieved [29, 37]. The first objective was addressed by findings showing that sustainable environmental knowledge has a significant effect when used in ART learning because it improves students' critical thinking as they explore 3D images and better conceptualize abstract environmental concepts taught in class. The second finding was also addressed by findings showing ART improved self-efficacy because it enhanced students' attention, making them more engaged in learning. The third objective was also achieved by finding that sustainable environmental knowledge did not significantly affect self-efficacy [24, 28]. Eventually, the study aim was addressed since the findings showed that ART's role in mediating the relationship between self-efficacy and sustainable environmental knowledge involved promoting critical thinking and attention during learning [30, 35]. The research question was also answered by results showing that ART use in sustainable environmental knowledge can improve students' self-efficacy. Moreover, the alternative hypothesis, H1A, was accepted, which meant that ART application in environmental knowledge should be encouraged because it can enhance students' attention, thereby improving their learning experience and academic outcomes [27, 33, 38]. Given that the research data analysis considered how sustainable environmental knowledge affects self-efficacy but did not assess behavioral effects. It is generally expected that teaching sustainable practices will have practical implications for students' behavioral changes. Due to limited time, long-term follow-ups to understand how sustainable environmental knowledge affects students' behavior are not conducted. On the other hand, the improvement in academic performance for students using AR is all related to AR technology. However, this may not be meaningful, as ART may simply encourage students to study more about the subject rather than providing unique educational content. Meanwhile, the first implication of this study is that environmental knowledge guidelines should be revised to include ART technology. The implication is based on results showing that incorporating ART into environmental knowledge improves self-efficacy due to increased attention and critical thinking Ali and Morshed [39]. The second implication was that the use of ART in learning should be aligned with course content to complement learning from class notes and other instructional materials. This strategy ensures that students can understand the practical application of their knowledge, such as how to reduce carbon emissions on a personal level, thereby increasing their confidence and enjoyment of learning [31, 32, 39].

4. Conclusions

Given the research results, we conclude that a recommendation for future research is that further analysis is needed on whether ART can be used to increase student performance at lower levels of education, as this study only considered higher education. In addition, future studies should use qualitative methods to collect detailed data. Specifically, qualitative research on this topic could help demonstrate how ART increases attention and why students express more critical thinking when incorporating technology into their learning. For future research, further analysis is needed to determine whether ART can improve student performance at primary and secondary education, as this study only focused on higher education. In addition, future research should use qualitative methods to collect detailed data. Specifically, qualitative studies could demonstrate how ART increases attention and why students express more critical thinking when incorporating technology into their learning.

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