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Research Article

The Potential of Portable AR in Physics Education: A Study on Student Perceptions

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ABSTRACT

Integrating portable augmented reality (AR) into physics education has the potential to enhance student engagement and learning outcomes. This study investigates students' perceptions of the appeal and effectiveness of the Traveling Virtual Lab (TVL), a solar-powered AR learning kit designed to improve physics education in the Philippines. A quantitative research design was employed, utilizing the "Student Acceptance of Virtual Laboratory questionnaire" adapted from Park (2009). The sample consisted of 58 students, with a balanced gender distribution and a majority at the tertiary-education level. Descriptive and inferential statistical analyses were performed to address the research questions. The results indicate that students perceive TVL as appealing and effective for learning physics concepts, with mean ratings of 3.9 for both variables. No significant differences were found in perceptions based on gender or grade. This study highlights the potential of portable AR to enhance physics education by providing immersive and interactive experiences that can visualize complex concepts and overcome resource constraints. However, challenges remain, including technological accessibility and the need for training teachers. These findings contribute to the growing body of literature on AR in education and have implications for the development and implementation of virtual laboratory technologies, particularly in resource-constrained settings. Future research should focus on addressing implementation challenges and exploring the long-term impact on student learning outcomes.

***Keywords**: Augmented Reality, Educational Technology, Learning Outcomes, Physics Education, Resource Constraints, Student Perceptions, Virtual Laboratory*

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Introduction

Laboratory activities play a crucial role in enhancing physics learning by providing hands-on experiences that help students understand scientific concepts better. Research indicates that both traditional and virtual laboratory settings can significantly impact student achievement and perceptions of learning. Simulation-based physics experiments, for instance, have been shown to positively influence students' learning achievements and perceptions of laboratory activities, offering a cost-effective and time-efficient alternative to physical labs (Asiksoy, 2023). Moreover, virtual labs provide a safe and interactive environment that enables students to conduct experiments multiple times, thereby deepening their understanding (Aljuhani et al., 2018). The adoption of advanced technologies such as virtual reality (VR) and augmented reality (AR) further enhances the learning experience by simulating real and fictitious physics scenarios. This innovative approach shifts the focus from confirmation-based tasks to explorative learning, helping students develop expert-like epistemologies of experimental physics (Canright and Brahmia, 2024; Jiang et al., 22021) Such labs are not only engaging but also effective in developing students' self-efficacy and realistic understanding of scientific processes.

Concerning the Philippines' performance in PISA 2018, the data revealed a significant proficiency gap between Filipino students' science scores and the OECD average. The average score of 357 points in science for Filipino 15-year-olds is markedly lower than the OECD average of 489 points, highlighting a substantial gap in educational outcomes (Chandir 2020). Factors contributing to these scores may include differences in curriculum emphasis, resource allocation, teacher training, and socioeconomic conditions. The Programme for International Student Assessment (PISA) 2022 revealed significant challenges in science education in the Philippines. Filipino students' proficiency in science is alarmingly low, with only 23% achieving at least Level 2 proficiency, starkly contrasting the OECD average of 76% (Bernardo et al., 2023). Furthermore, almost no students reached the top performance levels (Levels 5–6), indicating that many Filipino students struggle with basic science literacy (Bernardo et al., 2023). One of the key issues contributing to this underperformance is the resource constraints in the Philippine education system. Expenditure per student in the Philippines is the lowest among all PISA-participating countries, impacting the quality of science instruction and access to necessary resources such as laboratories (Bernardo et al., 2023). This systemic under-resourcing leads to significant barriers to improving the quality of science education in Australia.

Machine learning analyses have identified several factors that contribute to poor science performance among Filipino students, including metacognitive awareness of reading strategies, social experiences in school, aspirations, pride in achievements, and familial/home factors, such as parents' characteristics and access to ICT with internet connections. This highlights the importance of considering both personal and contextual factors in any plans to reform science education in the Philippines (Bernardo et al., 2023). Augmented Reality (AR) and Virtual Reality (VR) have significantly influenced educational frameworks, particularly by enhancing learning experiences in post-pandemic scenarios. Research underscores the multifaceted benefits of AR, such as increased student engagement and improved comprehension and retention of subject matter, especially in STEM education (Bajaj, 2023; Jiang et al., 2025). These technologies are particularly effective in creating interactive and immersive learning environments that encourage active participation and motivate students (Iqbal et al., 2024; Deng et al., 2024). However, integrating AR into education is not without its challenges. Technical issues, such as device compatibility, infrastructural diversity, and high initial investment costs, present significant barriers (Jiang et al., 2025; Rodriguez et al., 2023). Moreover, the usability of AR technologies varies across different learning styles and demographics, including gender, which is often overlooked in AR application studies (Tuli et al., 2022).

An innovative approach to augmented reality (AR) education that addresses certain barriers is the development of portable, solar-powered AR kits, exemplified by the Traveling Virtual Lab (TVL). This technology is particularly relevant in regions with limited infrastructure, such as the Philippines. However, there is a discernible gap in the literature regarding the effectiveness and user acceptance of such portable solutions (Reginald, 2023). Existing studies emphasize the necessity of user analytics and feedback to optimize these systems for broader applications (Papanastasiou et al., 2018; Algerafi et al., 2023). Future research should prioritize the development of AR technologies tailored to regional contexts and accommodate varying levels of technological accessibility. Moreover, addressing the digital divide by enhancing the accessibility and affordability of these technologies is essential for their widespread adoption (Crogman et al., 2025). This includes focusing on equitable access, comprehensive teacher training modules, and creating pedagogically sound digital content to seamlessly integrate AR into current educational practices (Algerafi et al., 2023). This research aims to investigate students' perceptions of the appeal and effectiveness of the Traveling Virtual Lab (TVL) in learning physics concepts. This study seeks to inform scalable, resource-sensitive strategies for enhancing science education in the Philippines by examining the practical implications and user experiences of this innovative augmented reality approach. By exploring student perceptions, this study aims to fill a gap in the literature and contribute to informing educational practices, fostering technology integration, and enhancing student engagement and learning outcomes in science education. This study analyzed student profiles, assessed the frequency and effectiveness of current laboratory activities, and evaluated the appeal and effectiveness of TVL. Additionally, it will examine potential differences in perceptions based on demographic factors and explore the relationships between appeal and effectiveness for both students and teachers. The findings of this study have the potential to significantly impact the development and implementation of virtual laboratory technologies in science education, particularly in resource-constrained settings.

Literature Review

Systematic Reviews of Virtual and Remote Laboratories

The integration of virtual laboratories into physics education is a growing trend, with numerous studies highlighting their pedagogical affordances and impact on learner outcomes. Virtual labs provide educational institutions with an adaptable tool that supports various learning modalities, accommodating students who may not attend on-campus classes by offering remote access to the necessary resources (Hassan et al., 2022). The pedagogical affordances of virtual labs are significant and include fostering a flexible learning environment that promotes technological integration in education through virtual reality (VR) and augmented reality (AR) tools (Zhang and Liu, 2024). This flexibility is particularly beneficial during necessary remote learning, such as during the COVID-19 pandemic, when traditional in-person lab experiences faced logistical challenges. Virtual labs offer practical alternatives to physical labs, allowing experimental tasks to be performed without spatial or temporal restrictions (Poo et al., 2023; Lai and Cheong, 2022). Moreover, virtual laboratories are effective in enhancing the learning outcomes. They support learning activities comparable to real laboratories, with reported improvements in student engagement and understanding of theoretical content. For instance, studies have revealed that virtual labs can bolster content knowledge and inquiry skills when integrated into traditional teaching practices, particularly with adequate teacher feedback (Asiksoy, 2023; Fadda et al., 22022) This integration is critical for improving perceptions and attitudes toward lab activities, ultimately contributing to a more effective learning process (Asiksoy, 2023; Alhashem and Alfailakawi, 2023). In the context of physics education, augmented reality, a facet of virtual labs, exemplifies how traditional materials can be adapted to modern learning approaches, allowing students to access resources beyond the constraints of traditional classroom settings (Lai and Cheong, 2022).

Augmented Reality-Based Learning Aids (AR-BLA)

Augmented Reality-Based Learning Aids (AR-BLA) have demonstrated promising potential to overcome the limitations of traditional STEM education, particularly in offering immersive and technologically enriched learning experiences. The integration of AR into STEM subjects has been shown to significantly enhance educational outcomes and student engagement. A review of numerous studies emphasizes that AR applications, especially when used in informal science education settings, can lead to positive learning outcomes and increased engagement (Goff et al., 2018). Another study highlights that smartphone and tablet-based AR solutions are the most commonly employed technologies in K-12 STEM learning, offering situated, task-based, and game-based learning strategies that positively affect both individual learners and the educational process (Jiang et al., 2025). AR has also been successfully integrated with computational thinking frameworks to enhance hands-on learning experiences in STEM courses in higher education. This integration supports the development of higher-order thinking skills, practical expertise, and engagement through approaches such as computational thinking scaffolding (Lee et al., 2023). Furthermore, AR fosters collaborative learning and critical thinking skills, as observed in robot programming activities, by enhancing group learning and maintaining engagement, although it can have unequal impacts depending on participants' access to resources (Radu et al., 2021). Despite these advantages, challenges are associated with the implementation of AR in education. These include issues related to teacher training, technical problems, classroom management, and costs associated with infrastructure and equipment (Sırakaya and Sırakaya, 2020). However, studies suggest that when these challenges are adequately addressed, AR can significantly motivate students and improve their interactions with STEM subjects. The potential of AR in education extends beyond the classroom, impacting student motivation, learning outcomes, and knowledge retention through immersive and interactive experiences (Algerafi et al., 2023). Additionally, initiatives such as MatAR aim to make STEM education more inclusive by providing color-blind-friendly AR solutions, thus promoting equitable and quality education (Mohammadi et al., 2023).

Sustainable, Low-Resource Laboratory Innovations

In developing countries, innovative approaches to laboratory resources have emerged, leveraging renewable energy technologies to address infrastructure and resource constraints. Solar-powered lab kits provide a sustainable solution by harnessing solar energy, a widely available resource, particularly in regions with high sun exposure. These kits are typically designed to operate efficiently with minimal energy consumption, which helps power essential laboratory equipment in off-grid or low-resource settings. For instance, wireless sensor network nodes powered by small solar panels connected to energy-harvester circuits demonstrate the potential of solar technology to provide self-powering capabilities essential for laboratory functions (Sharma et al., 2018). Furthermore, kiosk-style "lab-in-a-box" solutions present another innovative approach, particularly for off-grid schools. These portable laboratories are designed to be easily transportable and set up, providing a comprehensive suite of scientific tools and resources that can operate independently of traditional power grids. This setup is crucial for rural or remote educational institutions, where conventional laboratory facilities might be lacking. The integration of solar and other renewable energy sources into these systems not only ensures availability and sustainability but also aligns with the global goals of reducing carbon emissions and promoting clean energy (Pandey et al., 222022; Ugwoke et al., 2020). These innovations highlight the potential of renewable technologies to transform educational assets in developing countries and bridge the gap in scientific education and practice.

Philippine-Context Studies of Virtual/AR Labs

In the Philippines, the integration of virtual and augmented reality (VR/AR) into educational settings, especially within the K–12 curriculum, has attracted significant attention. The Department of Education (DepEd) has initiated pilot programs featuring virtual physics laboratories for senior high school students, marking a strategic shift towards enhancing educational engagement and effectiveness through digital innovation. These virtual labs provide a simulated environment for students to conduct experiments, fostering an interactive learning experience that may be more engaging than traditional methods (Maas & Hughes, 2020). Simultaneously, local studies on the usability of AR apps aligned with the K–12 curriculum have indicated a positive reception among students, boosting both motivation and comprehension capabilities (Deng et al., 2024; Badilla-Quintana et al., 2020). Research highlights the potential of AR and VR technologies to address diverse learning needs, including those of students with special educational requirements, thereby promoting inclusivity (Badilla-Quintana et al., 2020). Furthermore, a study conducted by Anselmo et al. (2024) examined the application of AR and VR in the Filipino context, aiming to assess the educational benefits and challenges these technologies present. Anselmo's work typically focuses on user engagement and effectiveness, offering insights that are crucial for curriculum design strategies involving VR/AR. Information regarding the Philippine context of virtual and AR labs in education is based on the available literature. Sustainable, Low-Resource Laboratory Innovations Case studies of solar-powered and low-cost lab kits in developing countries Evaluations of kiosk-style “lab-in-a-box” solutions for off-grid schools.

Methods

Research Design

Using a quantitative research design, this study aimed to quantify the relationship between variables and test hypotheses using statistical analysis (Kohler, 2022). The quantitative research design provided a structured and rigorous approach to investigate the perceptions of teachers and students regarding TVL and its AR features in physics education. By employing quantitative methods, this study aimed to generate objective and generalizable findings that contribute to the body of knowledge in this field.

Respondents of the Study

A systematic sampling strategy was used to select a representative sample of students who met the inclusion criteria for this study. Sample size calculations were conducted to ensure the statistical power and reliability of the findings.

Data Gathering Instrument

Quantitative data collection methods were employed to gather numerical data from participants. Surveys or questionnaires can be utilized to collect responses related to perceptions, ratings, and demographic information. These instruments are designed using Likert scales or other quantitative measures.

Data analysis

The research instrument utilized for data gathering in this study was the "Student Acceptance of Virtual Laboratory questionnaire," adapted from Park (2009). This questionnaire aimed to measure students' acceptance of virtual laboratory activities, particularly in the context of physics education. The instrument consists of 37 items rated on a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree").

The questionnaire was divided into two main sections: Part 1 focused on demographics for students, while Part 2 gathered feedback on technological usage and educational tools specifically from students.

Part 2 is structured into several sections, each containing Likert scale items related to various aspects of laboratory activities, including access to equipment, effectiveness of current activities, and frequency of hands-on experience.

The validity and reliability of the instrument were established through several means. First, the questionnaire items were adapted from study of Anselmo et..al (2024) an instrument previously validated by Park (2009) to ensure their content validity. Pilot testing was conducted to assess the clarity and validity of the survey items before their full implementation. Furthermore, the use of Likert-scale responses allowed for the quantitative analysis of responses, contributing to the reliability of the instrument.

Data Gathering Procedure

The data-gathering procedure for this quantitative research design involves a systematic approach to collecting numerical data from participants using carefully designed research instruments. First, research instruments, such as surveys or questionnaires, were developed based on the research questions and hypotheses outlined in the study. These instruments were designed to ensure clarity, relevance, and alignment with the study objectives. Prior to the full implementation, a pilot test was conducted with a small sample of participants to assess the clarity and validity of the survey items, incorporating any necessary revisions based on feedback. Following instrument preparation, the sampling strategy was determined, including identification of the population of interest and the criteria for inclusion. Using a systematic sampling approach, participants were selected at regular intervals until the desired sample size was achieved, ensuring representativeness and minimizing bias.

Once participants were selected, the data collection process began with the distribution of the finalized research instruments. Clear instructions were provided to the participants, along with assurances of confidentiality and anonymity, to encourage honest and thoughtful responses. Participants were given sufficient time to complete the survey, and data collection may have occurred through various means, including in-person distribution, email dissemination, or online survey platforms. Upon collection of completed surveys or questionnaire responses, data management procedures were implemented to accurately record and enter the data into a secure database or spreadsheet.

Subsequently, the collected data were subjected to descriptive statistical analysis to summarize the sample characteristics and key variables, followed by inferential statistical analysis to test the hypotheses and explore the relationships between variables. The interpretation of the analysis results was conducted in relation to the research objectives, with findings presented clearly using tables, graphs, and descriptive statistics. Finally, the implications of the findings are discussed, highlighting the limitations of this study and suggesting directions for future research. Overall, adherence to this systematic data-gathering procedure enables researchers to rigorously collect, analyze, and interpret quantitative data to address the research questions and contribute to advancements in the field of physics education and educational technology.

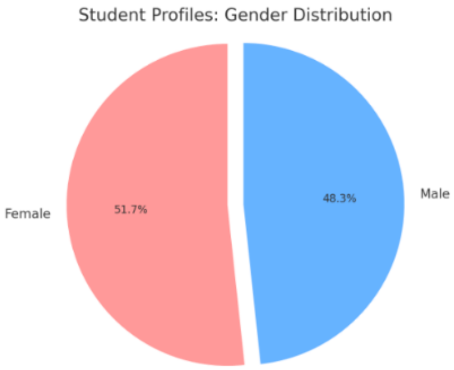
Statistical tools employed in this research encompassed both descriptive and inferential analyses to address specific research questions. Descriptive statistics, including frequencies and percentages, were used to profile students based on sex and grade level. Means and standard deviations summarize students' perceptions of the TVL's appeal and effectiveness in learning physics concepts compared to traditional laboratory activities. Similarly, descriptive statistics were used to assess the effectiveness of AR features in enhancing student engagement and understanding of physical concepts. For inferential analysis, chi-square tests or logistic regression analysis were used to examine the relationship between student profiles and their perceptions of the TVL. Additionally, Pearson correlation analysis or multiple regression analysis explored the relationship between students' perceptions of the TVL and their agreement on the effectiveness of AR features in enhancing engagement and understanding of physics concepts. These statistical tools provide a comprehensive approach to data analysis and effectively address the research questions.

Ethical Considerations

Participation was voluntary, with the right to withdraw at any time. No personal identifiers were recorded, the and data were stored on a password-protected drive accessible only to the research team. This study complied with the Declaration of Helsinki and the institutional ethical guidelines.

Results and Discussion

The students' profiles are listed in Figure 1&2. The gender distribution of respondents was balanced, with 51.7% female and 48.3% male. The majority of students (77.6%) were at the tertiary education level, followed by junior high (13.8%), and senior high (8.6%).



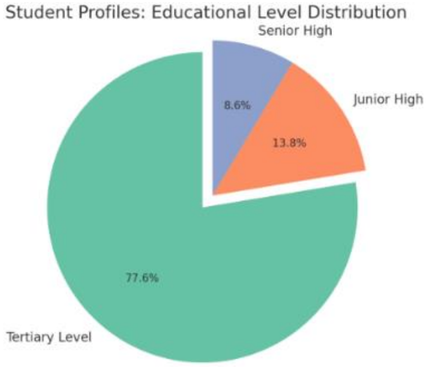


Table 1. Level of agreement between the students' frequency of laboratory activities and the current effectiveness of laboratory activities

Variable	Mean	Description	SD
Frequency of Activities	3.4	Agree	0.9
Learning from activities	3.8	Agree	1.0

Portable augmented reality (AR) has significant potential for enhancing physics education by engaging students and improving their learning experiences. Numerous studies have highlighted its applications and student perceptions of its effectiveness. For instance, research has shown that mobile AR integration in physics classes has elicited positive responses from students, improving their overall learning experience and providing a valuable tool for explaining complex scientific concepts (Bangga-Modesto 2024). AR applications offer a gamified learning experience that enhances cognitive and motivational results. A study involving the use of AR applications in K-12 education found that students and teachers positively received the technology, indicating a desire to integrate it into regular teaching processes (Volioti et al., 2022). In the realm of physics laboratory experiences, AR can reduce cognitive load and improve learning performance by providing real-time visualization and integration of virtual elements into physical experiments. Studies have demonstrated that AR-supported physics experiments, such as the visualization of electrical circuits, can aid conceptual learning and representation, thus enhancing students' understanding of complex topics (Lauer et al., 2020). Moreover, AR has been shown to effectively address learning anxiety, as its engaging nature can motivate students and lead to improved performance, regardless of their initial anxiety levels. This suggests that AR can create an inclusive and supportive learning environment that fosters positive student attitudes towards learning (Yu et al., 2022).

Table 2. Level of agreement of students' appeal and effectiveness of the Traveling Virtual Lab (TVL) for learning physics concepts

Variable	Mean	Description	SD
Appeal of the TVL	3.9	Agree	1.1
Effectiveness of the TVL	3.9	Agree	1.0

The integration of portable augmented reality (AR) in physics education has sparked considerable interest among educators and students, as it has the potential to enhance learning experiences. The Traveling Virtual Lab (TVL) represents one such implementation, designed to make abstract physics concepts more accessible through immersive and interactive experiences in a virtual environment. The study on student perceptions of TVL highlighted its appeal and effectiveness, with both variables receiving a mean rating of 3.9, indicating agreement among participants. Students perceive augmented reality as an engaging tool that enhances their motivation and understanding of physics concepts by allowing them to visualize and interact with complex scientific phenomena more concretely. The use of AR in educational settings can also facilitate collaborative learning approaches, enrich student-teacher interactions, and potentially elevate overall academic performance by making difficult concepts more graspable (Zatarain-Cabada et al., 22022; Wibowo, 2023; Lai and Cheong, 2022). Despite these promising benefits, the successful implementation of AR in education requires consideration of challenges such as technological accessibility and the need for teacher training (Lai and Cheong, 2022 ; Rodriguez et al., 22023) Overall, portable AR tools such as TVL demonstrate significant potential to enhance the physics learning experience by offering students interactive and appealing educational environments.

Table 3. T-test for Independent Samples results of the appeal of TVL in students in learning physics concepts when classified according to sex

Sex	M	t-value	df	Sig. (2-tailed)
Male	3.7	-1.30	55	.188
Female	4.1			

The study of the potential of Portable Augmented Reality (AR) through a Traveling Virtual Lab (TVL) offers rich insights into its applications and student perceptions in physics education. Augmented reality applications have been shown to significantly aid educational processes by creating interactive learning environments that enhance student engagement and motivation. In physics education, AR can be particularly effective in enabling students to visualize complex concepts and conduct virtual experiments that would otherwise be inaccessible (Lai and Cheong, 2022; Bajaj, 2023). Research indicates that using AR fosters higher levels of student motivation and engagement than traditional learning methods because it makes learning more immersive and interactive (Algerafi et al., 2023). For example, a study focusing on the use of AR in teaching dynamics and kinematics reported significant positive impacts on student motivation when AR environments were used, suggesting that such implementations could lead to deeper learning and a greater appreciation of the subject matter (Zatarain-Cabada et al., 2022). Meanwhile, the adoption of AR in laboratorysettings provides opportunities to overcome challenges linked to spatial and resource constraints, allowing students to perform experiments virtually that they might not be able to do in a physical laboratory (Lai and Cheong, 2022). Despite these benefits, challenges remain, such as ensuring the availability of devices and sufficient training for educators to effectively integrate AR into their teaching methods (Rodriguez et al., 2023). The T-test result in the study indicates no significant difference in the appeal of the TVL between male and female students for learning physics concepts, as reflected by a p-value of .188. This suggests comparable levels of acceptance and interest in AR tools among different genders (Zatarain-Cabada et al., 2022). Overall, the potential of portable AR in physics education seems promising, with broad implications for enhancing students' learning experiences.

Table 4. One-way Analysis of Variance (ANOVA) results of the appeal of TVL in students learning physics concepts when classified according to the grade level attended

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.158	2	.579	.47	.624
Within Groups	67.019	55	1.219		
Total	68.177	57			

Portable augmented reality (AR) has significant potential in physics education, providing innovative ways to engage students and enhance their learning experience. The use of AR in educational settings helps students understand complex physics concepts through interactive and immersive experiences. Research has demonstrated the benefits of AR in educational settings. For instance, AR-based learning environments, such as FisicARtivo, significantly boost student motivation by improving visual representation and facilitating interactive learning experiences (Zatarain-Cabada et al., 2022). AR technology promotes critical skills such as critical thinking, collaboration, communication, and creativity when integrated into physics learning, aiding the comprehension of concepts such as marine physics (Wibowo, 2023).Moreover, AR can help students visualize difficult and abstract concepts, such as electromagnetism, which are not easily observable. The technology offers visualizations that aid learning through shared understanding and improved communication, although it can occasionally distract from kinesthetic content (Radu and Schneider, 2023). Other studies have highlighted the technology's ability to integrate digital information with the physical world, minimizing cognitive load and promoting collaborative inquiry (Vidak et al., 2024). Despite these benefits, there are challenges to consider when implementing AR in physics education. Issues such as software and hardware limitations, such as camera freeze or visualization delays, can hinder learning (Vidak et al., 2024). In addition, the novelty of AR can lead to a tunnel vision effect, where students focus more on digital augmentation than on the main content.

Is there a significant difference in students' level of agreement on the effectiveness of the TVL when classified according to sex and grade level attended?

Table 5. T-test for Independent Samples results of the effectiveness of TVL in students in learning physics concepts when classified according to sex

Sex	M	t-value	df	Sig. (2-tailed)
Male	3.7	-1.08	55	.283
Female	4.0			

shows that there is **no significant different** in the effectiveness of TVL between male (M=3.7) and female (M=4.0) students, t (55) =-1.08, p = .283)

The T-test for independent samples assessing the effectiveness of the Travelling Virtual Lab (TVL) in students' learning of physics concepts shows no significant difference between male and female students. The mean effectiveness score for males was 3.7, and for females, it was 4.0. An independent samples t-test was conducted to compare the effectiveness of TVL between the two groups, resulting in a t-value of -1.08 with 55 degrees of freedom and a p-value of 0.283. These results indicate that the observed difference in effectiveness scores between male and female students is not statistically significant, suggesting that the TVL is equally effective across sexes. While the query specifies analysis by sex, current studies may emphasize effectiveness across other factors, such as motivation and training modules (Pande and Jepsen, 2024; Srinivasa et al., 22020)

Table 6. One-way Analysis of Variance (ANOVA) results of the effectiveness of TVL in students learning physics concepts when classified according to the grade level attended

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.015	2	.508	.47	.628
Within Groups	59.420	55	1.080		
Total	60.435	57			

Revealed that there was **no significant difference** in the effectiveness of the TVL when students were classified according to their grade level, F (2, 55) = .47, p = .628.

Table 6 presents the results of a one-way Analysis of Variance (ANOVA) examining the effectiveness of the Travelling Virtual Lab in teaching physics concepts to students when categorized by grade level. The analysis showed no statistically significant difference in the effectiveness of the lab across different grades. Specifically, ANOVA revealed an F-ratio of 0.47 with a p-value of 0.628, indicating that the observed differences in learning outcomes among the various grade levels were not statistically significant. The sum of squares between groups was 1.015 with 2 degrees of freedom, and the within-group sum of squares was 59.420 with 55 degrees of freedom, leading to a total sum of squares of 60.435 across 57 df.

Conclusion

This study investigated students' perceptions of the Traveling Virtual Lab (TVL), a portable augmented reality (AR) tool for physics education. The results indicate that students found the TVL appealing and effective for learning physics concepts, with mean ratings of 3.9 for both appeal and effectiveness. No significant differences were found in perceptions based on gender or grade level, suggesting the potential for broad applicability across student demographics. This study highlights the promise of portable AR in enhancing physics education by providing immersive and interactive experiences that can visualize complex concepts and overcome resource constraints. However, challenges remain, including technological accessibility and the need for training teachers. Overall, TVL and similar portable AR tools demonstrate significant potential to enhance physics learning experiences by offering students engaging and interactive educational environments. Future research should focus on addressing implementation challenges and further explore the long-term impact on student learning outcomes.

Recommendation and Future Research

Recommendations can be made for future research and practical applications. First, further studies should explore the long-term effects of the identified factors on organizational performance using longitudinal research designs to capture changes over time. Additionally, researchers could investigate the potential moderating or mediating variables that influence the relationship between key factors and organizational outcomes. Cross-cultural studies should be conducted to determine whether the findings are generalizable to diverse cultural contexts. From a practical standpoint, organizations should consider implementing strategies to enhance employee engagement, foster a positive work environment and promote effective leadership practices. Future research should focus on developing and testing interventions aimed at improving these critical areas. Finally, exploring the impact of emerging technologies and digital transformation on organizational dynamics can provide valuable insights for both scholars and practitioners in the rapidly evolving business landscape.

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tional value have been instrumental in evaluating the appeal and impact of portable augmented-reality tools in physics education.

References

Algerafi, M. A. M., Oubibi, M., Wijaya, T. T., & Zhou, Y. (2023). Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education. *Electronics*, *12*(18), 3953. https://doi.org/10.3390/electronics12183953

Aljuhani, K., Meccawy, M., Althabiti, M., & Sonbul, M. (2018). Creating a Virtual Science Lab (VSL): the adoption of virtual labs in Saudi schools. *Smart Learning Environments*, *5*(1). https://doi.org/10.1186/s40561-018-0067-9

Alhashem, F., & Alfailakawi, A. (2023). Technology-enhanced learning through virtual laboratories in chemistry education. *Contemporary Educational Technology*, *15*(4), ep474. https://doi.org/10.30935/cedtech/13739

Anselmo, C., Aquino, J. L., Dumelod, D., Abe, L., Ingente, M. A., Dimaano, V., … Anselmo, M. C. (2024). Evaluating the Impact of AR-Enhanced Virtual Traveling Labs on Physics Teaching and Learning. *Journal of Interdisciplinary Perspectives*, *3*(1), 266–273. https://doi.org/10.69569/jip.2024.0631

Asiksoy, G. (2023). Effects of Virtual Lab Experiences on Students' Achievement and Perceptions of Learning Physics. *International Journal of Online and Biomedical Engineering (IJOE)*, *19*(11). https://doi.org/10.3991/ijoe.v19i11.39049

Badilla-Quintana, M. G., Salazar Arias, M., & Sepulveda-Valenzuela, E. (2020). Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs. *Sustainability*, *12*(19), 8116. https://doi.org/10.3390/su12198116

Bajaj, A. (2023). Impact of Virtual Reality (Vr) and Augmented Reality (Ar) in Education. *Tuijin Jishu/Journal of Propulsion Technology*, *44*(4), 1310–1318. https://doi.org/10.52783/tjjpt.v44.i4.1014

Bangga-Modesto, D. (2024). Examining Student Perception on Mobile Augmented Reality Integration, Gender Differences, Learning Styles, Feedback, Challenges, and Opportunities in an Online Physics Class. *Science Education International*, *35*(1), 2–12. https://doi.org/10.33828/sei.v35.i1.1

Bernardo, A. B. I., Cordel, M. O., Calleja, M. O., Teves, J. M. M., Yap, S. A., & Chua, U. C. (2023). Profiling low-proficiency science students in the Philippines using machine learning. *Humanities & Social Sciences Communications*, *10*(1). https://doi.org/10.1057/s41599-023-01705-y

Canright, J. P., & White Brahmia, S. (2024). Modeling novel physics in virtual reality labs: An affective analysis of student learning. *Physical Review Physics Education Research*, *20*(1). https://doi.org/10.1103/physrevphyseducres.20.010146

Chandir, H. (2020). Student responses on the survey of global competence in PISA 2018. *Discourse: Studies in the Cultural Politics of Education*, *ahead-of-print*(ahead-of-print), 526–542. https://doi.org/10.1080/01596306.2020.1844153

Crogman, H. T., Sonawane, R. B., Boroon, R., Pacheco, E., & Cano, V. D. (2025). Virtual Reality, Augmented Reality, and Mixed Reality in Experiential Learning: Transforming Educational Paradigms. *Education Sciences*, *15*(3), 303. https://doi.org/10.3390/educsci15030303

Deng, W., Wang, L., & Deng, X. (2024). Exploring Interactive Learning Environments Based on Augmented Reality Technology. *International Journal of Interactive Mobile Technologies (IJIM)*, *18*(12), 15–29. https://doi.org/10.3991/ijim.v18i12.49911

Fadda, D., Salis, C., & Vivanet, G. (2022). About the Efficacy of Virtual and Remote Laboratories in STEM Education in Secondary School: A Second-Order Systematic Review. *Journal of Educational, Cultural and*

Psychological Studies (ECPS Journal), *26*. https://doi.org/10.7358/ecps-2022-026-fadd

Goff, E. E., Irvin, M. J., Mulvey, K. L., & Hartstone-Rose, A. (2018). Applications of Augmented Reality in Informal Science Learning Sites: a Review. *Journal of Science Education and Technology*, *27*(5), 433–447. https://doi.org/10.1007/s10956-018-9734-4

Hassan, J., Devi, A., & Ray, B. (2022). Virtual Laboratories in Tertiary Education: Case Study Analysis by Learning Theories. *Education Sciences*, *12*(8), 554. https://doi.org/10.3390/educsci12080554

Iqbal, A. I., Aamir, A., Hammad, A., Hafsa, H., Basit, A., Oduoye, M. O., Anis, M. W., Ahmed, S., Younus, M. I., & Jabeen, S. (2024). Immersive Technologies in Healthcare: An In-Depth Exploration of Virtual Reality and Augmented Reality in Enhancing Patient Care, Medical Education, and Training Paradigms. *Journal of Primary Care & Community Health*, *15*. https://doi.org/10.1177/21501319241293311

Jiang, H., Zhu, D., Chugh, R., Turnbull, D., & Jin, W. (2025). Virtual reality and augmented reality-supported K-12 STEM learning: trends, advantages, and challenges. *Education and Information Technologies*, *30*(9), 12827–12863. https://doi.org/10.1007/s10639-024-13210-z

Jiang, S., Sung, S. H., Xie, C., Tatar, C., & Huang, X. (2021). Augmented Reality in Science Laboratories: Investigating High School Students' Navigation Patterns and Their Effects on Learning Performance. *Journal of Educational Computing Research*, *60*(3), 777–803. https://doi.org/10.1177/07356331211038764

Lai, J. W., & Cheong, K. H. (2022). Educational Opportunities and Challenges in Augmented Reality: Featuring Implementations in Physics Education. *IEEE Access*, *10*, 43143–43158. https://doi.org/10.1109/access.2022.3166478

Lauer, L., Altmeyer, K., Javaheri, H., Grünerbl, A., Brünken, R., Lukowicz, P., Malone, S., Amiraslanov, O., & Peschel, M. (2020). Real-time visualization of electrical circuit schematics: An augmented reality experiment setup to foster representational knowledge in introductory physics education. *The Physics Teacher*, *58*(7), 518–519. https://doi.org/10.1119/10.0002078

Lee, H.-Y., Wu, T.-T., Wang, W.-S., Huang, Y.-M., & Lin, C.-J. (2023). Integrating Computational Thinking into Scaffolding Learning: An Innovative Approach to Enhance Science, Technology, Engineering, and Mathematics Hands-On Learning. *Journal of Educational Computing Research*, *62*(2), 211–247. https://doi.org/10.1177/07356331231211916

Jiang, H., Zhu, D., Chugh, R., Turnbull, D., & Jin, W. (2025). Virtual reality and augmented reality-supported K-12 STEM learning: trends, advantages, and challenges. *Education and Information Technologies*, *30*(9), 12827–12863. https://doi.org/10.1007/s10639-024-13210-z

Maas, M. J., & Hughes, J. M. (2020). Virtual, augmented, and mixed reality in K–12 education: a review of the literature. *Technology, Pedagogy and Education*, *29*(2), 231–249. https://doi.org/10.1080/1475939x.2020.1737210

Marín Rodriguez, W. J., Calvo Rivera, I. P., Andrade Girón, D. C., Susanibar Ramirez, E. T., Caro Soto, F. G., Ausejo Sanchez, J. L., & Zúñiga Rojas, Z. R. (2023). Artificial Intelligence and Augmented Reality in Higher Education: a systematic review. *Data and Metadata*, *2*, 121. https://doi.org/10.56294/dm2023121

Mohammadi, K., Fadlallah, J., Bonakala, S., Ayeche, L., Bentria, E. T., Medina, J., & El Mellouhi, F. (2023). MatAR: dynamic augmented reality platform for accessible molecular visualization. *Physical Chemistry Chemical Physics*, *25*(43), 29415–29423. https://doi.org/10.1039/d3cp02435k

Pande, P., & Jepsen, P. M. (2024). Science lab safety goes immersive: An ecological media-comparison study with gender analyses assessing iVR's learning effectiveness. *Research and Practice in Technology Enhanced Learning*, *20*, 001. https://doi.org/10.58459/rptel.2025.20001

Pandey, A. K., Tyagi, V. V., Salam, P. A., Ahamed, J. U., Said, Z., Juanico, D. E., Tyagi, S. K., Rahman, S., Krismadinata, K., Samykano, M., Reji Kumar, R., Sharma, K., & Kalidasan, B. (2022). Solar Energy Utilization Techniques, Policies, Potentials, Progresses, Challenges and Recommendations in ASEAN Countries. *Sustainability*, *14*(18), 11193. https://doi.org/10.3390/su141811193

Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., & Papanastasiou, E. (2018). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality*, *23*(4), 425–436. https://doi.org/10.1007/s10055-018-0363-2

Poo, M. C.-P., Chen, Q., & Lau, Y.-Y. (2023). Are Virtual Laboratories and Remote Laboratories Enhancing the Quality of Sustainability Education? *Education Sciences*, *13*(11), 1110. https://doi.org/10.3390/educsci13111110

Radu, I., Schneider, B., & Hv, V. (2021). Unequal Impacts of Augmented Reality on Learning and Collaboration During Robot Programming with Peers. *Proceedings of the ACM on Human-Computer Interaction*, *4*(CSCW3), 1–23. https://doi.org/10.1145/3432944

Reginald, G. (2023). Teaching and learning using virtual labs: Investigating the effects on students' self-regulation. *Cogent Education*, *10*(1). https://doi.org/10.1080/2331186x.2023.2172308

Sharma, H., Jaffery, Z. A., & Haque, A. (2018). Solar energy harvesting wireless sensor network nodes: A survey. *Journal of Renewable and Sustainable Energy*, *10*(2), 023704. https://doi.org/10.1063/1.5006619

Sırakaya, M., & Alsancak Sırakaya, D. (2020). Augmented reality in STEM education: a systematic review. *Interactive Learning Environments*, *30*(8), 1556–1569. https://doi.org/10.1080/10494820.2020.1722713

Srinivasa, A. R., Jha, R., Ozkan, T., & Wang, Z. (2020). Virtual reality and its role in improving student knowledge, self-efficacy, and attitude in the materials testing laboratory. *International Journal of Mechanical Engineering Education*, *49*(4), 382–409. https://doi.org/10.1177/0306419019898824

Tuli, N., Sharma, S., & Mantri, A. (2022). Augmented reality in education: a systematic study on technical and usability issues. *International Journal of Computer Aided Engineering and Technology*, *17*(2), 164. https://doi.org/10.1504/ijcaet.2022.125048

Ugwoke, B., Corgnati, S. P., Adeleke, A., Pearce, J. M., & Leone, P. (2020). Decentralized Renewable Hybrid Mini-Grids for Rural Communities: Culmination of the IREP Framework and Scale up to Urban Communities. *Sustainability*, *12*(18), 7411. https://doi.org/10.3390/su12187411

Vidak, A., Movre Šapić, I., Mešić, V., & Gomzi, V. (2024). Augmented reality technology in teaching about physics: a systematic review of opportunities and challenges. *European Journal of Physics*, *45*(2), 023002. https://doi.org/10.1088/1361-6404/ad0e84

Volioti, C., Sotiriou, C., Spiridis, V., Sapounidis, T., Melisidis, K., Zafeiropoulou, M., & Keramopoulos, E. (2022). Using Augmented Reality in K-12 Education: An Indicative Platform for Teaching Physics. *Information*, *13*(7), 336. https://doi.org/10.3390/info13070336

Wibowo, F. C. (2023). Effects of Augmented Reality Integration (ARI) based Model Physics Independent Learning (MPIL) for facilitating 21st-century skills (21-CS). *Journal of Technology and Science Education*, *13*(1), 178. https://doi.org/10.3926/jotse.1800

Zatarain-Cabada, R., Cárdenas-Sainz, B. A., Chavez-Echeagaray, M. E., & Barrón-Estrada, M. L. (2022). Experiences of web-based extended reality technologies for physics education. *Computer Applications in Engineering Education*, *31*(1), 63–82. https://doi.org/10.1002/cae.22571

Zhang, N., & Liu, Y. (2024). Design and implementation of virtual laboratories for higher education sustainability: a case study of Nankai University. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1322263