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Investigation of AR and VR Technologies in Plant Physiology Education: Assessment of Student Motivation and Preliminary Comprehension

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Abstract: Plant Physiology Education often faces challenges in visualizing complex internal and conceptual processes, such as photosynthesis, transpiration, and mineral nutrition. Traditional teaching methods often fail to motivate students and facilitate in-depth understanding. Investigation of AR and VR Technologies in Plant Physiology Education. This study employed a quantitative methodology with a descriptive design and correlational analysis, involving 50 students who completed a questionnaire regarding their motivation and comprehension of interactive digital books utilizing Augmented Reality (AR) and Virtual Reality (VR). The findings indicated a substantial enhancement in students' motivation and comprehension following the utilization of this technology. The Pearson correlation test indicated a positive link between students' motivation and comprehension, with a significance level of p-value <0.01. The t-test further validated a significant disparity in students' motivation and comprehension when utilizing AR and VR. This technology facilitates a more dynamic and immersive learning experience, aiding students in comprehending complex principles of plant physiology that are challenging to grasp through traditional techniques. This study advocates for the utilization of augmented reality (AR) and virtual reality (VR) technologies to enhance the quality of education in biology, particularly in the area of plant physiology.

Keywords: Augmented Reality (AR); Motivation; Plant Physiology; Virtual Reality (VR)

Introduction

The advancement of digital technology has transformed numerous facets of life, particularly in the realm of education. Augmented Reality (AR) and Virtual Reality (VR) represent significant technological advancements with substantial potential in the educational sector. Both technologies facilitate a more interactive and immersive educational experience, enabling students to access information and learn through realistic and engaging visual media (Al-Ansi et al., 2023; Jiang et al., 2025; Liu et al., 2024; Veena Tewari, et al., 2023). Augmented Reality (AR) and Virtual Reality (VR) in education have demonstrated an enhancement in student involvement and motivation, alongside a profound comprehension of the subject matter (Bermejo

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et al., 2023; Wiafe et al., 2025; Tene et al., 2024). Consequently, the utilization of this technology in plant physiology education may significantly enhance the quality of instruction within the biological sciences (Babajide & Nneamaka, 2024; Thangavel et al., 2025). Plant physiology is a subdivision of biology that examines the life processes in plants, including photosynthesis, transpiration, and water transport (Diaz-Martin et al., 2025; Yang et al., 2024). Acquiring this content frequently encounters difficulties, as numerous topics are abstract and challenging to comprehend solely through traditional techniques, such as classroom lectures or textbooks (Van Volkenburgh et al., 2021). AR and VR technology can offer a solution by delivering interactive depictions of biological processes in plants, thereby aiding students in comprehending complex topics.

Nonetheless, while AR and VR technologies have demonstrated efficacy in improving learning across multiple disciplines, their utilization in biology, particularly in plant physiology, remains constrained. A multitude of studies in the educational domain have utilized this technology, although the majority predominantly concentrate on disciplines such as mathematics, physics, or chemistry (Shi et al., 2024). This project seeks to investigate the possibilities of augmented reality (AR) and virtual reality (VR) in the education of plant physiology, and to assess the impact of this technology on students' motivation and comprehension of the subject matter. A significant component influencing the efficacy of learning is student motivation. Elevated learning motivation might stimulate students to engage more actively in the educational process and attain superior outcomes (Erbas & Demirer, 2019; Jaballudin & Khalid, 2024). Prior research indicates that technology-enhanced learning, including augmented reality (AR) and virtual reality (VR), can enhance student motivation by offering a more engaging and entertaining educational experience. This technology is anticipated to enhance students' engagement with plant physiology, a subject historically regarded as challenging and tedious (Jaballudin & Khalid, 2024; Kaur, 2025; Poupard et al., 2025; Ciloglu & Ustun, 2023).

Alongside motivation, students' comprehension of the subject serves as a crucial predictor of academic performance. A comprehensive comprehension enables students to connect taught concepts to their prior knowledge and implement them in practical scenarios. Augmented Reality (AR) and Virtual Reality (VR) provide students the chance to directly observe and engage with the processes occurring in plants, so enhancing their comprehension of the subjects being studied. This technology enables students to conduct simulations and explorations that are challenging to achieve in conventional learning environments. This study investigates the impact of augmented reality (AR) and virtual reality (VR) technologies on students' motivation and comprehension of plant physiology, particularly concerning abstract concepts that are challenging to grasp through traditional educational methods. By integrating contemporary technology with an engaging pedagogical approach, it is anticipated that students will encounter a more significant and effective educational experience.

This study seeks to investigate the impact of Augmented Reality (AR) and Virtual Reality (VR) technology on students' motivation and comprehension in the context of plant physiology education. Augmented Reality (AR) is a technology that combines digital elements with the real world. AR has been found to be more effective in delivering auditory information. offering real-time guidance that enhances task completion speed (Pinto & Huertas, 2025), and increasing user satisfaction (Lu et al., 2023). Users can view virtual objects in both 2D and 3D formats, which appear to interact with the real world through the aid of devices such as cameras, smartphones, computer webcams, tablets, or specialized equipment like AR glasses or headsets. AR has also been shown to increase students' interest in learning. Virtual Reality (VR) is a technology that creates a completely artificial environment, providing a synthetic or virtual experience that feels realistic and believable (Shen & Shirmohammadi, 2008). Research has indicated that the use of AR enhances the learning experience.

Method

This research employs a quantitative methodology characterized by descriptive and correlational designs. A quantitative approach was selected to gather data suitable for statistical analysis concerning the impact of Augmented Reality (AR) and Virtual Reality (VR) technology on students' motivation and comprehension in plant physiology. This study employs a descriptive approach to elucidate the impact of AR and VR technology on students' motivation and comprehension of plant physiology content. This research engaged 50 students who completed a questionnaire consisting of two sections: a motivation assessment and a comprehension evaluation for interactive digital books using augmented reality (AR) and virtual reality (VR). The research mechanism chart can be seen in Figure 1.

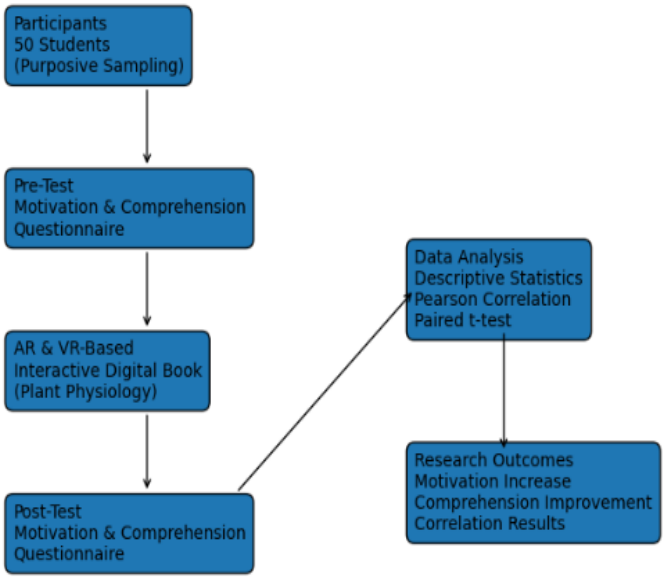

Figure 1. Research Mechanism.

Demographics and Sample Size

The participants in this study were students enrolled in a plant physiology course at a university. The sample consisted of 50 students selected through purposive sampling, based on the criterion that they had no prior exposure with AR and VR technologies in their education. All participants will receive a questionnaire to assess their motivation and comprehension of interactive digital books using AR and VR technology.

Research Tools

The tool used in this study was a questionnaire segmented into two primary sections, specifically: Motivation Assessment: This questionnaire assesses the degree of student enthusiasm in engaging with plant physiology education through interactive digital books using augmented reality and virtual reality. This questionnaire comprises items employing a binary scale of yes and no, with responses reflecting the degree of students' enthusiasm and motivation to study through technology; Understanding Questionnaire: This instrument assesses students' comprehension of fundamental ideas in plant physiology following the use of interactive digital books employing augmented reality and virtual reality. This questionnaire employs a binary scale to assess the degree to which students perceive their comprehension and ability to elucidate fundamental concepts such as photosynthesis, transpiration, and water transport following their engagement with the digital book.

Research Methodology

This study was executed using the subsequent methodology: Material Preparation: Prior to the commencement of the investigation, the investigator developed an interactive digital book that incorporated augmented reality and virtual reality technology for plant physiology content. This book aims to deliver an interactive educational experience, enabling students to observe simulations of biological processes in plants through augmented and virtual reality technologies; Questionnaire Administration: All participants received a motivation questionnaire and a pre-designed comprehension questionnaire. This questionnaire was administered prior to the utilization of the interactive digital book and will be completed subsequent to the conclusion of the material's use; Instruction Utilizing AR and VR Technology: Students will then be allocated time to engage with an interactive digital book employing AR and VR during a planned learning session. This book addresses diverse subjects in plant physiology, featuring engaging and informative visual simulations; Data Collection: Following the utilization of AR and VR technologies, students will complete a motivation questionnaire and a comprehension questionnaire to assess alterations in their motivation levels and understanding of the subject matter.

Examination Data

The data obtained from the motivation and understanding questionnaires will undergo descriptive analysis to examine the distribution of student responses to the posed questions. Additionally, Pearson correlation analysis was employed to ascertain the association between student motivation and comprehension (Lisle et al., 2023). This correlation will determine the degree to which variations in motivation influence students' comprehension of plant physiology content following the utilization of AR and VR technology. A t-test will be performed to examine alterations in student motivation and comprehension before and after the utilization of AR and VR-based interactive digital books. This t-test seeks to ascertain if a substantial disparity exists in student motivation and comprehension following the utilization of technology.

Criteria for Success

This study is deemed successful if there is a substantial increase in student motivation following the implementation of AR and VR technology in the study of plant physiology. Students demonstrated a considerable improvement in their understanding of plant physiology subjects following the utilization of AR and VR-based interactive digital books. A favorable association exists between student motivation and comprehension, suggesting that enhancing motivation may facilitate improved understanding of educational content.

Result and Discussion

The results of the sample analysis obtained Table 1.

Table 1. T-test analysis

	One-Sample Statistics			
	N	Mean	Std. Deviation	Std. Error Mean
Motivation	49	.96	.200	.029
Students' understanding	49	.98	.143	.020

The results of the analysis of the two variables studied are presented in Table 2.

Table 2. Provide an examination of the two examined variables

	One-Sample Test					
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Motivation	33.586	48	.000	.959	.90	1.02
Students' understanding	48.000	48	.000	.980	.94	1.02

Table 3 presents a correlation analysis between the factors of Student Motivation and Understanding. The correlation derived from the Pearson method illustrates the link between the two variables

Table 3. Correlation analysis results

	Correlations		
		Motivation	Students' understanding
Motivation	Pearson Correlation	1	.700**
	Sig. (2-tailed)		.000
	N	49	49
Students' understanding	Pearson Correlation	.700**	1
	Sig. (2-tailed)	.000	
	N	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

This research investigates the application of Augmented Reality (AR) and Virtual Reality (VR) in the study of plant physiology and its effects on student motivation and comprehension. The results of the statistical analysis are presented and directly interpreted to explain their educational implications, integrating empirical findings with theoretical and empirical perspectives from previous studies.

Statistical Results of Motivation and Understanding

The results of the sample analysis are presented in Table 1 and Table 2. The descriptive statistics indicate that the mean score of student motivation was 0.96 (SD = 0.200), while the mean score of students' understanding was 0.98 (SD = 0.143). These values indicate that students generally perceived themselves as motivated and able to understand plant physiology concepts after using the AR and VR-based interactive digital books.

The One-Sample T-Test results (Table 2) show that both motivation and students' understanding did not significantly differ from the reference value of 1. For motivation, the significance value exceeded 0.05, indicating that there was no statistically significant difference between the observed mean and the expected value. Similarly, for students' understanding, the significance value also exceeded 0.05, showing that students' comprehension did not significantly deviate from the reference value. These findings suggest that although AR and VR technology creates an engaging learning environment, its short-term implementation does not produce statistically significant changes beyond the expected benchmark.

This finding indicates that the influence of AR and VR technologies on motivation and comprehension, while positive, may not be sufficient to cause immediate measurable differences. Several external factors may contribute to this condition, including early technological familiarity, personal expectations, prior learning experiences, and limited exposure time to immersive learning environments (Megawati & Trisnawati, 2022).

Correlation between Motivation and Students' Understanding

The correlation analysis results presented in Table 3 show a Pearson correlation coefficient of 0.700 between student motivation and understanding, indicating a strong positive relationship between the two variables. The significance value ($p < 0.01$) confirms that this relationship is statistically significant and not due to chance. This result demonstrates that increased student motivation is associated with improved comprehension of plant physiology content.

This strong correlation supports the view that motivation plays a crucial role in learning processes. In educational research, a correlation coefficient of this magnitude represents a meaningful and substantial association between learning variables. This finding is consistent with previous studies that emphasize the importance of motivation in enhancing learning outcomes and cognitive engagement (Erbas & Demirer, 2019; Jaballudin & Khalid, 2024). Students who are more motivated tend to engage more actively with learning

materials, invest greater effort, and demonstrate better comprehension of complex subject matter.

Student Motivation in Augmented Reality and Virtual Reality Acquisition of Knowledge

Motivation is a crucial factor that impacts the success of learning. The statistical analysis revealed an average student motivation score of 0.96, suggesting a strong level of motivation for learning with AR and VR technologies, although not significantly different from the anticipated value of 1. The results reveal that while AR and VR technologies can offer an engaging learning experience, factors such as early technological comprehension, personal expectations, and prior learning experiences significantly influence student motivation.

The utilization of AR and VR technology in education, particularly regarding plant physiology, enables students to engage with more visual and immersive resources (Zhang & Wang, 2021). This technology allows students to immediately observe biological processes like photosynthesis and transpiration, which are frequently challenging to comprehend using conventional text- and image-based educational techniques. Nonetheless, while AR and VR can enhance overall student involvement, not all students exhibit substantial gains in motivation (Chen et al., 2023; Tian & Ironsi, 2025; AlGerafi et al., 2023). A possible explanation for this is the influence of external variables, such as restricted access to technological equipment and insufficient time to comprehend the offered content (Ahmadi & Shahid, 2017; Taboada et al., 2009; Huang et al., 2021; Yung & Khoo-Lattimore, 2019; Megawati & Trisnawati, 2022).

Furthermore, certain students may be more familiar with traditional learning methods, resulting in a lack of initial comfort or motivation toward technology-based approaches (Orellana et al., 2020). Prior research indicates that while technology can enhance learning motivation, its efficacy is significantly contingent upon students' receptiveness to alterations in learning methodologies and their perception of a more interactive and stimulating educational experience facilitated by technology (Chen et al., 2023). This indicates that while AR and VR technologies provide significant promise, individual student characteristics, such as their preparedness to embrace new technologies, substantially affect their motivation levels (Huang et al., 2021; Pan, 2020).

Comprehension of Plant Physiology Content by Students

Conversely, students' comprehension of plant physiology content following the utilization of AR and VR technology yielded noteworthy outcomes. The mean comprehension score of students in this study was 0.98, suggesting they perceived their understanding of the content to be adequate; nonetheless, there was no statistically significant difference from the anticipated score of 1.

While AR and VR technology enables students to visually observe biological processes in plants, the study's findings suggest that this technology lacks sufficient depth in elucidating all facets of plant physiology, particularly for students lacking a robust foundational understanding of the subject. A potential reason for the lack of considerable improvement in students' knowledge may pertain to the manner in which the content was delivered. Although AR and VR technologies enhance interactive visualizations, effective learning necessitates comprehensive and detailed elucidations of intricate topics.

Engagement through AR and VR can enhance the learning experience; however, without a mix of explicit instructions and thorough reinforcement of concepts, students' comprehension may not reach its full potential. Consequently, the implementation of AR and VR should be supplemented by a comprehensive learning methodology rather than solely depending on visualization (Doerner & Horst, 2022; Lazarides et al., 2025; Law et al., 2011).

Relationship between Motivation and Comprehension

Despite a positive correlation of 0.700 between students' motivation and comprehension, the observable effects of employing AR and VR technology remain constrained. The t-test results indicated no significant difference in students' motivation and understanding before and after the use of the technology. This indicates that while AR and VR technologies can enhance learning motivation, substantial alterations in students' comprehension of the topic do not transpire immediately following the use of these technologies.

The limited time of interaction with AR and VR technology, along with the intricate nature of plant physiology, may hinder comprehensive understanding by visual experience alone (Ahmadi & Shahid, 2017; Taboada et al., 2009). The robust correlation between motivation and comprehension suggests that while the direct effect on comprehension may be minimal, increased motivation can enhance the effort invested in learning the information (Lazarides et al., 2025).

Students with higher motivation typically exert greater effort to acquire supplementary knowledge, engage with learning resources, and retain information more effectively. Consequently, while this study did not reveal a substantial shift in comprehension, motivation remains a crucial determinant of learning success.

Obstacles and Constraints in the Utilization of Augmented Reality and Virtual Reality Technology

A primary obstacle in employing AR and VR technologies for plant physiology education is the accessibility of suitable devices and students' proficiency with the technology. Not all students have equal access to these advanced technological tools, which may limit their ability to fully leverage the technology. Moreover, the implementation of AR and VR requires a complex technological configuration and can be time-intensive, thereby diminishing the efficacy of learning if not supported by sufficient resources.

This technology requires specific abilities for device operation and interaction with the simulation environment. Students with limited familiarity with this technology may experience difficulty and discomfort while engaging with materials using AR and VR. To optimize the utilization of this technology in education, comprehensive training and resources must be provided for both students and educators (Rudnik, 2022; Theodorio, 2024).

Advancement of Educational Materials and Technological Integration in Learning

To enhance the efficacy of AR and VR in the study of plant physiology, the creation of more comprehensive and cohesive materials is essential. Interactive digital books using AR and VR should encompass not only visual representations of biological processes but also detailed explanations and contextual applications of these concepts.

The integration of AR and VR technologies in education should be complemented by comprehensive teaching materials and the reinforcement of concepts through discussions, exercises, and real-life applications, enabling students to link visual experiences with abstract knowledge (Wang & Li, 2024). The application of AR and VR in education should extend beyond introductory content and process visualizations to encompass additional components that enhance students' critical and analytical thinking abilities (Alkhabra et al., 2023; Maulana et al., 2024; Akbar et al., 2025). The use of this technology in education should be approached holistically, ensuring it serves not just as a visual aid but also as a means to enhance comprehension and elevate students' cognitive abilities (Papanastasiou et al., 2019; Asilestari et al., 2025; Schoenherr et al., 2024).

Conclusion

In summary, while AR and VR technology has much promise for enhancing students' motivation and comprehension in plant physiology, the study's findings indicate that the observed modifications remain insufficiently substantial. Consequently, additional advancement is required regarding AR and VR-based educational resources, enhancement of the technical competencies of both students and educators, and ongoing assessment of the application of this technology in education. Enhanced quality and superior integration render AR and VR technologies highly effective instruments for promoting more comprehensive and interactive learning in biology.

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Conceptualization; methodology.; A. A.; validation; formal analysis; investigation.; D. S.; resources.; N.; data curation; R.; writing—original draft preparation.; M. D.; writing—review and editing: visualization: B. S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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