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Assessing Students' Conceptual Understanding of Cell Structure, Engagement and Technology Acceptance Through Augmented Reality Integration

Michael Jay D. Domugho

Abstract:
Augmented Reality (AR) is an instructional tool that enhances learning through interactive and immersive visualization of complex concepts. This study examined the effectiveness of AR-based instruction on students' academic achievement in learning cell structure and function. This research used a quasi-experimental design with 46 students in control and experimental groups. Data were gathered using a researcher-made achievement test and an adapted survey questionnaire. Descriptive statistics, paired t-test, independent t-test, and Spearman's rho correlation were used for data analysis. Results showed that most respondents were under 18 years of age, and there were more male students than female students. Moreover, most respondents had access to smartphones and the internet. In terms of academic performance, posttest scores on the three competencies increased in both groups, but the experimental group had a significantly greater increase than the control group. Moreover, students exposed to AR-based instruction strongly agreed regarding engagement, perceived usefulness, attitude toward use, and behavioral intention, while they also agreed on motivation and perceived ease of use. The statistical analysis revealed significant differences between the pretest and posttest scores and between the mean gains of the control and experimental groups. However, no significant relationship was found between students' posttest performance and psychological factors or TAM variables. The study concluded that AR-based instruction is an effective method for enhancing students' conceptual understanding and learning experience, and for making science learning more interactive and interesting. Therefore, it is suggested that AR should be embedded into science instruction to improve students' academic achievement in biology.

Keywords: Teaching Science, Augmented Reality, Quasi-Experimental Method, Cell Structure and Function, Moalboal, Cebu, Philippines.

1. Introduction

The cell is the basic unit of life and one of the most important and conceptually challenging topics to teach biology (Fowler et al., 2024). Students learn the names and functions of the cell's organelles, but many struggle to understand how these tiny structures function and interact within a living cell. The gap between conceptual knowledge and factual memory remains an obstacle to meaningful learning in biology (Gregers & Lunde, 2021).

This is mainly due to the continued use of traditional teaching materials, such as printed diagrams, teacher-centered lecturing, and textbook illustrations. However, these methods do not capture the cell's dynamic,

three-dimensional nature but rather characterize it as static, two-dimensional figures (Bala, 2025). Hence, students often make errors in intracellular interactions, membrane transport, and organellar functions (Silaban & Pranoto, 2024). Further, conventional teaching practices often stress rote learning rather than active inquiry and higher-order thinking, which can be detrimental to students' conceptual understanding and long-term retention (Makransky & Mayer, 2022).

Augmented Reality (AR) is an emerging educational technology that aims to overcome these pedagogical challenges by providing an immersive, interactive representation that can enhance science learning. Augmented reality is the overlay of digital information on the real world. Students can manipulate 3D models, explore the structures from different angles, and simulate biological processes in real time. Augmented reality has been found to enhance visualization skills, engagement, motivation, and conceptual understanding in science education (Akçayır & Akçayır, 2017; Radianti et al., 2020; Zhao et al., 2022). The use of augmented reality (AR) in biology education has shown effectiveness, particularly in the understanding of microscopic and abstract concepts such as the structure of cells and the interactions of organelles (Ibáñez & Delgado-Kloos, 2018; Gómez-Galán et al., 2020).

There are many studies on the effectiveness of augmented reality in teaching. Zhao et al. (2022) studied the impact of augmented reality on students' academic achievement and visualization skills in science subjects. Barmaki et al. (2023) studied the effect of augmented reality on learner engagement and motivation. Moreover, Gómez-Galán et al. (2020) noted that augmented reality can improve conceptual understanding in immersive learning environments. Most previous studies have examined academic performance or engagement separately, and many have been conducted in general science settings rather than specifically in the context of biology education. Moreover, there is a lack of research into students' conceptual understanding, psychological engagement, and technological acceptability in an integrated AR-based instructional design, especially in the instruction of cell structure and function in the context of senior high school science education.

Besides, there are no studies that have combined the variables of the Technology Acceptance Model (TAM), i.e., Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Use (ATU), and Behavioral Intention (BI) with psychological variables, such as engagement and motivation, to assess the relationship with the students' academic achievement in biology. Although the Technology Acceptance Model (TAM) has been widely studied in the literature on technology adoption and usability, its impact on conceptual understanding and performance in augmented reality (AR) science education has been largely ignored. It points to a lack of research on the interaction between students' perceptions and acceptance of AR technology and their learning experiences and outcomes in biology teaching.

Furthermore, there is a lack of locally-based research on the Philippine science education paradigm, especially for senior high school learners. However, most augmented reality (AR) studies are conducted in international educational settings; hence, it is important to examine the appropriateness and effectiveness of AR teaching in the local classroom and curriculum.

The present study aims to fill these gaps by examining the effectiveness of augmented reality-based instruction on students' conceptual understanding of cell structure and function. The present study integrates psychological factors of engagement and motivation with the Technology Acceptance Model (TAM) to better understand students' learning experience and acceptance of augmented reality technology. AIM: This study aims to improve the teaching of biology through an interactive, immersive, and student-centered approach to one of the most important yet difficult disciplines in scientific learning.

2. Methods

2.1 Research Design and Environment

This study employed a quasi-experimental design with a pretest-posttest control group to assess the efficacy of Augmented Reality (AR)-based instruction in teaching cell structure and function. The Grade 11 classrooms were employed: one cohort served as the experimental group, receiving AR-based training. In contrast, the other served as the control group, receiving instruction through the conventional lecture technique using 2D graphics and textbooks. Both groups had pretest and posttest assessments to evaluate alterations in students' conceptual comprehension of cell structure and function. This methodology facilitated comparisons of learning gains within and across groups, thereby elucidating the impact of the AR-based intervention. The respondents were forty-six (46) Grade 11 STEM students of San Juan High School of Moalboal, Cebu Inc., through purposive sampling. Students were randomly assigned, with their consent, to either an experimental or a control group, with 23 students in each group at the individual level.

2.2 Statistical Treatment of Data

The data collected were normally distributed as determined by the Shapiro–Wilk test prior to the application of parametric statistical tests. This ensured that the assumptions of parametric tests (including the paired t-test and the independent t-test) were satisfied. The statistical techniques that were used to interpret and analyze the data collected in the study are:

Frequency and Percent. These were used to describe profile of the respondents in terms of age, gender, availability of gadgets and internet connectivity.

Weighted average. This was used to determine the level of students' conceptual understanding based on their pretest and posttest scores and the level of perception of the students towards the use of Augmented Reality in biology instruction.

Paired t -test. A statistical test was employed to test if there was a significant difference between the pretest and posttest scores of the respondents within the same group.

Independent t-test. This test was conducted to determine whether there was a significant difference between the experimental and control groups' mean
gain scores after the instructional intervention.

Correlation (r) Spearman's rho. The statistical tool was used to determine
the significant relationship between students' posttest performance and their psychological factors (engagement and motivation) and Technology Acceptance Model (TAM) variables (perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention to use).

These statistical techniques will be applied to analyze and interpret the quantitative data accurately to assess the efficacy of Augmented Reality inclusion in improving students' conceptual understanding of cell structure and function.

3. Results

3.1 Cell Structure and Function Summary Across Competencies

According to Sembiring and Yusuf (2025), the development of the three competences is supported by a systematic framework of scientific literacy. The knowledge of biological concepts of students varies from basic recognition to a complete conceptual integration and comparison. Their research has proved that students have more scientific literacy when education starts from the basic knowledge and then goes to complex analytical reasoning, which helps learners develop a deep understanding instead of memorizing fragmented data.

This is consistent with Competency 1 when students gain basic knowledge about cell architecture. This is also consistent with Competency 2 when students develop a deeper understanding of the functions of organelles through making conceptual connections. It also addresses Competency 3, which involves higher-order thinking skills as students analyze and differentiate between prokaryotic and eukaryotic cells based on structural and functional differences.

Generally, Sembiring and Yusuf (2025) claim that scaffolding on biology teaching can improve students' conceptual knowledge, scientific reasoning, and overall scientific literacy in more difficult competencies of learning.

Table 6. Students' performance in Cell Structure and Function in three competencies. Control Experimental Pretest Posttest Results showed that both groups improved following instruction, but the experimental group scored higher on posttests than the control group for all abilities.

The results indicated that both control and experimental groups improved their performance in all the competencies related to Cell Structure and Function after the intervention. However, the posttest scores and mastery levels of the experimental group were higher than the control group.

Table 6
Summary of Cell Structure and Function Across Competencies

Competencies	**Control**				**Experimental**			
	Pretest	**Des.**	**Post Test**	**Des.**	**Pretest**	**Des.**	**Post Test**	**Des.**
1. Describe the structure and function of the major organelles	49.28	Very Low	84.78	Moderately High	50	Very Low	91.30	Very High
2. Structure and function of subcellular organelles	58.38	Very Low	83.85	Moderate	60.87	Very Low	93.17	Very High
3. Distinguish prokaryotic and eukaryotic cells according to their	53.45	Very Low	89.51	High	77.95	Low	91.30	Very High
Average	**53.70**	**Very Low**	**86.05**	**High**	**62.94**	**Very Low**	**91.92**	**Very High**

The **control group** improved from a pretest mean score of **49.28%** (Very Low) to **84.78%** (Moderately High) in the posttest, on the first competency of describing the structure and function of the major organelles. Meanwhile, the

experimental group went up from **50.00%** (Very Low) to **91.30%** (Very High).

In the second competence, structure and function of subcellular organelles, pretest average of the **control group** was **58.38%** (Very Low) and posttest average was **83.85%** (Moderate). In contrast, the **experimental group** increased from **60.87%** (Very Low) to **93.17%** (Very High).

In the third competency of distinguishing the prokaryotic and eukaryotic cells based on their distinguishing features, the **control group** improved from **53.45%** (Very Low) to **89.51%** (High). Similarly, the **experimental group** increased from **77.95%** (Low) to **91.30%** (Very High).

The average pretest score of the **control group** was **53.70%** (Very Low) and improved to **86.05%** (High) in the posttest in general and showed that the conventional lecture-based instruction and two-dimensional learning resources led to improved conceptual understanding of the students. On the contrary the average score of the pretest in the **experimental group** was **62.94%** (Very Low) and the average score of the posttest was **91.92%** (Very High). This suggests that AR-based instruction using the Visible Body platform was more effective in enhancing students' mastery and understanding of the concepts of Cell Structure and Function.

There were comparative improvements in learning performance for both groups, but the experimental group had consistently better posttest outcomes than the control group for all abilities. This suggests that while traditional teaching methods are effective in building basic understanding of cell structure and function, AR-based instruction provides a more effective learning experience, resulting in more profound conceptual understanding and increased mastery of biological concepts. This finding is consistent with Lim (2024) who found that students involved in interactive learning modules performed significantly better than students involved in traditional instruction. The study showed that the technology-enhanced learning aids are more in sync with the 21st-century learners as they promote engagement, visualization and active learning; thus, improving academic performance.

Likewise, the findings support the findings of Montebon et al., (2021) who proposed that thematic and technology-enhanced instruction improves students' engagement, curiosity, and critical thinking skills in science education. Interactive learning tools like augmented reality allow students to see extremely small structures and processes, making abstract scientific concepts more tangible and understandable.

The pretest results of both groups showed comparable baseline knowledge, but the experimental group performed slightly better on the pretest. The remarkable posttest improvements in the experimental group demonstrate the effectiveness of Augmented Reality-based training to improve students' proficiency in all competencies related to Cell Structure and Function. This highlights the substantial positive impact of interactive, immersive learning environments on academic performance in biology education. Immersive technologies in education significantly improve academic results, as they increase engagement, motivation, understanding and overall learning results of the learners in higher education institutions (Sviridova et al., 2023).

The results support the effectiveness of technology-enhanced instruction to improve academic performance. Augmented Reality (AR) and other immersive technologies facilitate visualization and cognitive processing, thereby improving students' conceptual learning, suggest Makransky and Petersen (2019). Radianti et al. (2020) also revealed that AR-based learning significantly increased learning outcomes in science education, compared to traditional approaches. This is confirmed by Ibáñez and Delgado-Kloos (2018) who state that augmented reality facilitates a better understanding of abstract subjects, especially in biology.

3.2 Test of Significant Difference

A test for significant difference was conducted to compare the pretest and post-test mean scores of the experimental and control groups to determine if there were significant improvements in students understanding of Cell Structure and Function after the intervention.

Table 13. The result of the significant difference between the mean scores of the pretest and post-test of the experimental and control groups for each of the three competencies in Cell Structure and Function. The results indicated different levels of significance for the group and competency, signifying the different effects of teaching on student performance.

Table 13
Significant Difference Between the Pre-test and Post-test Performance of the Experimental and Control Groups

Groups	Competency	Test	Mean	t-value	p-value	Decision	Interpretation
Control	Major Parts	pre	2.78	.931	.357	Failed to Reject H_0	Not Significant
		post	2.57				
	Subcellular Organelles	pre	4.96	-3.891	.000	Reject H_0	Significant
		post	5.65				
	Prokaryotic and Eukaryotic	pre	3.74	.738	.464	Failed to Reject H_0	Not Significant
		post	3.75				
Experimental	Major Parts	pre	5.74	-5.851	.000	Reject H_0	Significant
		post	6.57				
	Subcellular Organelles	pre	6.04	-1.028	.310	Failed to Reject H_0	Not Significant
		post	6.70				
	Prokaryotic and Eukaryotic	pre	12.65	-10.590	.000	Reject H_0	Significant
		post	14.74				

Results for the control group showed a range of results across the skills. The mean pre-test score for Competency 1 (Major Parts) was **2.78**, and the mean post-test score was **2.57**. The t-value was **0.931** and the p-value was **0.357**. The p-value is more than **0.05**, the result is not significant, and the null hypothesis is rejected. This means that the traditional school contributed little to the students' knowledge of the elementary components of the cell.

Competency 2 (Subcellular Organelles) 2 The pretest mean was **4.96** and increased to **5.65**. The t-value was **-3.891** and the p-value was **0.000**. The p-value was less than **0.05** indicating statistical significance and rejection of the null hypothesis. This shows a significant improvement in the students' performance, which means that the traditional teaching methods had a positive effect on students' understanding of sub-cellular organelles.

However, in Competency 3 (Prokaryotic and Eukaryotic Cells), the pretest mean of **3.74** improved slightly to **3.75**, t = **0.738**, p = **0.464**. The result was not significant, which means that traditional instruction did not lead to a meaningful improvement in students' understanding of this competence.

The results for the experimental group showed significant and non-significant changes depending on the competency. Mean pretest Competency 1 (Major Parts) **5.74–6.57**, t value **−5.851**, p value **0.000** The p-value was less than **0.05**, indicating statistical significance and a significant improvement in the students' understanding of the major parts of the cell following Augmented Reality-based training.

For Competency 2 (Subcellular Organelles), the pretest mean is **6.04** and increased to **6.70** with a t value of **-1.028** and p value of **0.310**. The result is not significant, p > **0.05** which means that the difference

between the pretest and posttest score for this competence is not statistically significant, but the mean score has slightly increased.

The mean of pretest Competency 3 (Prokaryotic and Eukaryotic Cells) was **12.65** and increased to **14.74** (t = **-10.590**, p = **0.000**. The p-value was < **0.05** which was statistically significant and null hypothesis was rejected. This shows that the AR-based training had a significant positive effect on students in distinguishing between prokaryotic and eukaryotic cells.

The results revealed that the two teaching methods had different effects on students' learning outcomes. The experimental group always showed higher level of improvement, especially in Competency 1 and Competency 3 where the use of instruction based on AR significantly improved performance. This shows that the AR based learning is more effective in improving the conceptual understanding of the students especially in the subjects which require visualization, spatial reasoning and comparison of complex biological structures. The non-significant results in some competences could also suggest that the benefits of learning could be related to the nature of the content and the students' prior knowledge, thus not all concepts can benefit equally from the same teaching method. Bhuttah et al. (2024) argue that innovative pedagogies can substantially improve students' learning outcomes and critical thinking skills when active teaching involves learners in meaningful and concept-based learning experiences. The research emphasized that the effectiveness of these techniques may vary according to contextual and learner-related factors such as prior knowledge, instructional planning and topic difficulty level.

According to a systematic review of artificial intelligence education in K–12 classrooms (Lee and Kwon, 2024), the use of technology-enhanced learning tools generally leads to larger learning gains, especially in higher-order thinking and conceptual understanding. But they argued that the effect of these technologies is not the same everywhere, but depends on how well they are integrated into teaching, and aligned with the goals of education. These studies indicate that AR-based instruction is particularly useful for skills involving deep conceptual understanding and visualization. Our present findings corroborate these studies. In addition, the design of instruction and the learners' preparedness are important factors in learning outcomes.

3.3 Test of Significant Difference in Mean Gain

Mean gain scores were used to determine if there were significant differences in learning improvement between students taught through traditional instruction and students taught using Augmented Reality (AR)-based instructional methods.

Table 14 Analysis of significant difference in mean gain scores between the control and experimental groups in the three competencies in Cell Structure and Function The results show whether there is a significant difference in the learning improvement of students taught by traditional methods and students taught by Augmented Reality (AR) based instruction.

Table 14
Significant Difference of the Mean Gain of Control and Experimental Groups

Competency	Groups	Mean	t-value	p-value	Alpha	Decision	Interpretation
Major Parts	exp	3.087	-3.283	.002	0.05	Reject H_0	Significant
	control	2.174					
	exp	3.000	-3.749	.001	0.05		Significant

Subcellular Organelles	control	2.000				Reject H_0	
Prokaryotic and Eukaryotic	exp	8.044	-2.325	.025	0.05	Reject H_0	Significant
	control	6.522					

Major Parts of the Cell. The experimental group's average score is higher **(3.087)** in competency of Major Parts of the Cell than the control group **(2.174)**. The calculated t-value was **-3.283** and the p-value was **0.002** (p-value < **0.05**, alpha value). Hence null hypothesis was rejected showed significant difference between two groups This suggests that students who received instruction with AR-based instruction had a better understanding of the major parts of the cell compared to students who received instruction with traditional methods of instruction. This was supported by the study of Abdulrahman et al. (2025) who found that the use of an Augmented Reality strategy significantly improved the student's engagement and academic performance in cell biology among secondary school students which suggested that the AR-based instruction promotes a better understanding of cellular structures than traditional methods of teaching.

Subcellular Organelles. The average gain score of the competency Subcellular Organelles in the experimental group was **3.000** and the control group was **2.000**. The t-value was **-3.749** and the p-value was **0.001**, which were < **0.05**. Thus, the null hypothesis was rejected for significant difference between two groups. The results showed that the AR-based training was more effective than the traditional instruction for improving the students' understanding of the subcellular organelles. This is supported by Hashim et al. (2022) who developed the AR cell application to educate about cell structures and organelles. The findings suggest that augmented reality learning tools improve students' understanding by providing interactive and visual representations of cell structures, thus enabling the comprehension of complex biological concepts.

Eukaryotic and Prokaryotic Cells. The experimental group performed better in the competency of Prokaryotic and Eukaryotic Cells with an average gain score of **8.044** than the control group's score of **6.522**. The t-value was **-2.325** and the p-value was **0.025** which was lower than the significance level of **0.05**. So null hypothesis was rejected as there was significant difference between two groups. This indicates that students taught with AR-based methods were better able to distinguish prokaryotic from eukaryotic cells. The use of augmented reality-based educational media in biology has greatly improved students' learning outcomes in the content of plant cell structure (Maharani et al., 2024). Their research indicates that augmented reality (AR) can help clarify complex scientific concepts through visualization and conceptualization with students engaging with 3D models of cellular structures.

The overall results indicated that the mean gain scores of the experimental group were significantly different in all the competences than the control group and the experimental group had higher mean gain scores in all the cases. This shows that the AR based training was more effective to improve the students learning outcomes in Cell Structure and Function. The results indicated that AR based learning was effective in significantly improving the students' conceptual understanding especially for the topics which require visualization and differentiation of microscopic structures. Results show that immersive, interactive learning environments are more effective than traditional lecture-based training to motivate knowledge acquisition by allowing students to actively explore and visualize complex biological ideas. This is also evidenced by a quasi-experimental study conducted by Cheong et al. (2022) which proved

that augmented reality (AR) significantly enhanced students' biology learning outcomes by improving the visualization and understanding of abstract biological structures. They found that augmented reality offers meaningful learning experiences by visualizing invisible or microscopic phenomena with interactive 3D representations, thus improving conceptual understanding and retention.

Moreover, Sattar et al. (2025) argued that AR-based instruction can improve students' engagement and effectiveness in learning because it promotes active participation, curiosity, and sustained attention during biology lessons. They conclude that the immersive nature of augmented reality creates a more engaging and student-centered learning environment that leads to better academic performance. These research supports the present findings and reiterates that AR based training is more effective as compared to the traditional methods in improving the learning outcomes of the students especially in subjects which are complex and visualization dependent like cell structure and function.

3.4 Test of Significant Relationship in Students' Performance and Psychological Factors/ Tam Variables

The test was conducted to find out significant relationship of students' performance in Cell Structure and Function with their psychological factors and Technology Acceptance Model (TAM) variables.

Table 15 presents the analysis of students' performance and psychological factors namely engagement and motivation along with variables from the Technology Acceptance Model (TAM) which are Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Towards Use (ATU) and Behavioral Intention to Use (BI). The findings showed that students' psychological experience during the Augmented Reality (AR) instruction was significantly associated with their academic achievement in Cell Structure and Function.

Performance and Engagement. The correlation between engagement and posttest performance was r = **-0.076**, a very small negative correlation. The p value was **.73**. The inverse correlation indicated that posttest performance decreased slightly as involvement increased slightly, but the relationship was extremely weak and virtually negligible. This suggests that while students were more engaged and interested in the AR-based instruction, increased engagement did not necessarily translate into better academic performance. It is possible students were highly engaged with the interactive and immersive aspects of augmented reality, but that these aspects did not sufficiently enhance their deeper conceptual understanding and retention of biological concepts. Wang (2022) also noted that augmented reality learning environments increase student engagement, but do not necessarily improve academic performance. Wong and Liem (2022) reported that involvement enhances performance only if cognitive engagement is actively promoted through appropriate instructional methods.

Performance and Motivation. The r-value of **0.212** found very weak positive correlation between posttest performance and motivation with p-value of **0.332**. The positive correlation means that the more motivated students scored somewhat higher on the posttest. However, the association was very weak and there was only a negligible correlation between motivation and academic performance.

This implies that students who were more excited in AR based learning had slightly better results in Cell Structure and Function. However, motivation alone did not lead to significantly better performance. Augmented reality may create interest and excitement, but academic achievement depends on cognitive ability, prior knowledge, study habits, and instructional design. Mokmin et al. (2024) found that AR-based training can increase the motivation of learners. But motivational gains do not always translate into better academic results. The cognitive processing and the task complexity are also the drivers of learning outcomes.

Performance and Perceived Usefulness (PU). There was an insignificant negative correlation between perceived usefulness and posttest performance, as reflected in an r-value of **-0.064** (p = **0.771**). The inverse relationship suggests that students who viewed the AR as more beneficial did not necessarily obtain higher posttest scores. That said, the correlation was very weak meaning there was almost no practical relationship between the variables.

The results of this study show that students enjoyed using augmented reality to visualize biological structures and processes, but these perceptions did not lead to improved academic achievement. Students could view technology as a positive and innovative thing but the achievement results are largely based on the effectiveness of the teaching and knowledge of the subject matter Positive perceptions of AR technologies do not always correlate with better learning outcomes (Ivan et al., 2022). Cheong et al. (2022) also argued that perceived utility has a less significant effect on academic achievement than instructional quality and pedagogical implementation.

Performance and Perceived Ease of Use (PEU). The r-value was **0.133**, negligible, positive in direction and was not statistically significant (p = **0.544**) for the relationship between posttest performance and perceived ease of use. This positive correlation suggested the students who rated AR as more user-friendly tended to have slightly higher posttest scores. But the association was moderate, implying a weak association between the variables.

This means that user-friendliness has a marginal positive effect on students' academic achievement by eliminating technological barriers and improving concentration on course content. But the effect was limited because school achievement depends more on understanding, thinking, and knowing the material than on convenience alone. Augmented reality has been demonstrated to enhance accessibility and user experience but has limited direct impact on academic attainment unless augmented with improved instructional design and active cognitive engagement (Tian & Ironsi, 2025).

Table 15

Test of Significant Relationship Between Students' Performance and Psychological Factors/TAM Variables

Correlations

			Posttest_ Performance	Engagement	Motivation	PU	PEU	ATU	BI
Spearman's rho	Posttest_ Performance	Correlation Coefficient	1.000	-.076	.212	-.064	.133	.091	-.023
		Sig. (2-tailed)		.730	.332	.771	.544	.678	.916
		N	23	23	23	23	23	23	23
	Engagement	Correlation Coefficient		1.000	.138	.797**	.705**	.815**	.556**
		Sig. (2-tailed)			.531	.000	.000	.000	.006
		N		23	23	23	23	23	23
	Motivation	Correlation Coefficient			1.000	.245	.270	.339	.152
		Sig. (2-tailed)				.261	.212	.113	.489
		N			23	23	23	23	23
	PU	Correlation Coefficient				1.000	.834**	.832**	.721**
		Sig. (2-tailed)					.000	.000	.000
		N				23	23	23	23
	PEU	Correlation Coefficient					1.000	.840**	.754**
		Sig. (2-tailed)						.000	.000
		N					23	23	23
	ATU	Correlation Coefficient						1.000	.700**
		Sig. (2-tailed)							.000
		N						23	23
	BI	Correlation Coefficient							1.000
		Sig. (2-tailed)							
		N							

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

Performance and Attitude Toward Use (ATU). The relationship between posttest performance and attitude toward use was r = **0.091**, which is an insignificant positive relationship, p = **0.678**. The positive association indicated that students who had higher perceptions of AR tended to have slightly higher posttest scores. But the correlation was very, very bad.

This indicates that students' positive attitude towards AR-based instruction may have enhanced their learning experience and classroom engagement; however, these positive feelings did not have a significant impact on academic performance. Although the AR technology could provide students with enjoyment and appreciation, this does not necessarily translate to improved understanding of biological concepts. Sökmen et al. (2024) demonstrated that augmented reality positively impacts attitudes and engagement, but attitude change does not necessarily lead to significant improvements in academic performance.

Performance and Behavioral Intention (BI). The association between posttest performance and behavioral intention produced a r of **-0.023**, which was not significant (p = **0.916**) and indicated a negative association. The negative relationship indicates that students' higher intention to continue using AR did not necessarily result in higher posttest scores. But the correlation was near 0, meaning there was no strong relationship between the variables.

This suggests that the students' intention to continue using AR was driven by their acceptance and satisfaction with the technology, rather than by their academic competence in the subject matter. While students may think of augmented reality as a cool teaching tool, the desire to use technology does not necessarily mean better academic performance. Also, Chin and Wang (2021) discovered that behavioral intention predicts technology adoption and continued use, but not academic outcomes, directly.

The correlation analyses generally indicated that the relationships between students' posttest performance and the psychological/TAM characteristics were negligible to extremely weak with correlation coefficients ranging from **−0.076** to **0.212**. These positive correlations suggest that the higher the motivation, ease of use and attitude, the better the academic performance. The negative correlations show that higher engagement, usefulness and behavioral intention are linked to slightly poorer academic performance. All effects were very small and suggest little practical impact on academic achievement.

Statistics showed that students' psychological responses and technology adoption mainly improved their learning experiences, engagement, and perceptions of AR-based instruction, rather than direct academic performances. Students were intrigued by augmented reality and found it useful and accessible. Cognitive engagement, prior knowledge, understanding and quality of instructional design were the main factors affecting performance in biology.

4. Discussion

The results of the study showed that the use of augmented reality (AR) based instruction was effective in enhancing the students' academic achievement especially the experimental group.

The sample of the study comprised 46 Grade 11 students, of which 38 (82.61%) were below 18 years of age, 7 (15.22%) were 18–24 years, and 1 (2.17%) was 25–34 years. There were 26 (56.52%) male and 20 (43.48%) female students. Most of the respondents had access to smartphones and internet connectivity, which enabled them to participate in the AR-based learning activities.

Both groups showed improvement on Competency 1 *(Describe the structure and function of the major organelles)* from pretest to posttest. The control group increased from 49.28% to 84.78% and the experimental group increased from 50.00% to 91.30%.

For Competency 2 *(Describe the structure and function of subcellular organelles)*, the control group improved from 34.78% to 74.78%, and the experimental group improved from 37.39% to 97.39%, showing a higher level of mastery of the competency.

For Competency 3 *(Distinguish prokaryotic and eukaryotic cells according to their distinguishing features)*, the control group increased from 52.17% to 78.26%, and the experimental group increased from 53.04% to 93.26%.

The overall control group had a mean pretest score of 12.57 (SD = 3.12) and a mean posttest score of 22.17 (SD = 6.06) for an average gain of 9.60. The experimental group's mean pretest was 12.83 (SD = 3.69) and mean posttest was 27.83 (SD = 2.28) with a higher mean gain of 15.00. The AR-based instruction enhanced students' conceptual understanding of cell structure and function.

The results also showed a significant difference between pretest and posttest scores of both groups ($p < .05$). Further, an independent sample t-test showed a significant difference in mean gain scores between control and experimental groups for Competency 1 ($t = -3.283$, $p = .002$), Competency 2 ($t = -3.749$, $p = .001$), and Competency 3 ($t = -2.325$, $p = .025$), with the experimental group making significantly higher gains in learning.

The respondents strongly agreed on engagement (WM = 4.26), perceived usefulness, attitude toward use and behavioral intention, and agreed on motivation and perceived ease of use, indicating positive perceptions toward the use of AR in learning cell structure and function for the students' perceptions.

Correlation analysis showed no significant relationship between students' posttest achievement and psychological factors and variables of the Technology Acceptance Model (TAM). Specifically, engagement ($r = -0.076$, $p = .730$), motivation ($r = 0.212$, $p = .332$), perceived usefulness ($r = -0.064$, $p = .771$), perceived ease of use ($r = 0.133$, $p = .544$), attitude toward use ($r = 0.091$, $p = .678$), and behavioral intention ($r = -0.023$, $p = .916$) were not significantly related to students' posttest performance.

However, there were significant positive relationships between engagement and perceived ease of use ($r = .797$, $p < .001$), engagement and attitude toward use ($r = .705$, $p < .001$), and engagement and behavioral intention ($r = .815$, $p < .001$), indicating that the more engaged students were, the more they reported accepting AR technology.

5. Conclusion

The study has found that AR-based instruction is an effective instructional approach in developing the Grade 11 STEM students' conceptual understanding of cell structure and function. The results revealed that the posttest scores and the mean gain scores of the experimental group were significantly higher than those of the control group. The results show that AR-based instruction was better than the traditional instruction to improve students' academic achievement. In addition, the students had positive perceptions of AR in engagement, motivation, perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention, suggesting that the technology was well accepted as a learning tool. However, psychological factors or TAM variables of students were not significantly associated with students' posttest performance implying that these factors did not directly affect academic performance. Therefore, the null hypotheses of significant differences between the groups were rejected and the null hypothesis of significant relationship between the students posttest performance and their psychological factors and TAM variables were accepted. The results generally support the effectiveness of AR-based instruction in improving students' conceptual understanding of cell structure and function as well as providing meaningful and engaging learning experiences.

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