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Enhancing Biology Instruction: The Impact of Computer-Aided Instruction and Strategic Intervention Materials on Student Learning

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Abstract. Despite the growing integration of digital learning tools in science education, research on their comparative impact remains limited. The quasi-experimental design involved 32 Grade 9 students from Candaping National High School, Candaping B, Maria, Siquijor, who were grouped based on their prior Science performance. Participants were divided into two groups: one receiving CAI-based instruction and the other utilizing SIMs. Pre-test and post-test scores were analyzed using mean, standard deviation, and t-tests for dependent and independent data to measure learning gains. Results indicate that students exposed to CAI demonstrated a 14.00% improvement, while those using SIMs showed a 12.33% increase. Statistical analysis revealed a significant difference ($p < 0.05$), suggesting that CAI was more effective in fostering conceptual understanding. These findings demonstrate the potential of CAI to transform science education by utilizing technology to enhance learning outcomes in complex topics like photosynthesis and cellular respiration while highlighting the effectiveness of both CAI and SIMs in bridging learning gaps, offering educators practical and flexible tools to improve student performance.

Keywords: Computer-aided instruction; Intervention materials; Science education; Strategic instructional methods.

1.0 Introduction

The 21st century presents numerous educational challenges, with declining student interest and participation in science emerging as a global concern (Mahawan & Celedonio, 2023). Stagnant scientific performance has been a persistent issue in the United States since the 1990s. At the same time, countries like Australia, parts of the Western world, and ASEAN nations such as Singapore and Thailand continue to face difficulties in sustaining student engagement in science, emphasizing the need for innovative teaching strategies (De Jesus, 2019; Schneider et al., 2020; Benong et al., 2024).

Despite efforts to improve education, the Philippines continues to face challenges in science proficiency among students. The 2022 Program for International Student Assessment (PISA) results emphasize a concerning trend, with the Philippines experiencing a 0.8% decline in science proficiency, ranking it in the bottom 10 out of 81 countries for the second time (Servallos, 2023; Acido & Caballes, 2024; Benong et al., 2024). This issue is not new; in the World Economic Forum's Global Competitiveness Reports, the Philippines ranked 67th out of 140 in 2015-2016, 79th out of 138 in 2016-2017, and 56th out of 137 in 2017-2018 for science education quality (Aranda et al., 2019). De Jesus (2019) identified a consistent pattern of underperformance in science among Grade 9 students, as reflected in the National Achievement Test results from SY 2015–2018. The scores revealed a significant lack of content mastery and academic underachievement. These challenges are also evident in Candaping National High School, Maria, Siquijor, where photosynthesis and cellular respiration have been identified as the least mastered competencies in Science 9 during the first quarter. Additional research by Verano and Comighud (2020) attributed this poor performance to several school-based factors, including inadequate teaching and learning facilities, students' socioeconomic status, parental educational backgrounds, student motivation and attitude, school type, and teacher characteristics. According to Noviante et al. (2022), the poor learning outcomes of these students suggest that educators need to implement diverse teaching strategies and models to enhance instructional quality.

Despite the increasing use of Computer-Aided Instruction (CAI) and Strategic Intervention Materials (SIMs) in science classrooms, their comparative or combined effectiveness remains underexplored. Technology integration into education has transformed traditional teaching methods and enhanced learning outcomes. Studies have shown that CAI, as a key information and communication technology (ICT) tool, facilitates effective learning by supporting curricula and improving standardized test scores (Bariham et al., 2019; Mezieobi et al., 2019; Suson & Ermac, 2020; Arthur-Baidoo et al., 2022). This SIM further enhances this effectiveness, providing educators with valuable resources for explaining complex scientific concepts and addressing academic achievement gaps (De Jesus, 2019; Mahawan & Celedonio, 2023). While prior research has examined the benefits of CAI and SIMs, limited studies have compared their effectiveness or explored their combined use in teaching complex biological processes, such as photosynthesis and cellular respiration. To address this gap, this study investigates the effectiveness of CAI and SIMs in improving students' conceptual understanding of photosynthesis and cellular respiration.

Photosynthesis and cellular respiration are among the most challenging topics for Grade 9 students (Santos et al., 2021) and continue to be difficult for college freshmen (Malones, 2022), creating significant learning barriers in both secondary and higher education (Arthur-Baidoo et al., 2022). Overcoming these difficulties is crucial for developing more effective instructional methods and strengthening students' grasp of scientific concepts. While past studies have emphasized the advantages of innovative teaching strategies, limited research has explored the combined use of Computer-Aided Instruction (CAI) and Strategic Intervention Materials (SIMs) in facilitating learning of these topics. This research aims to address this gap through a quasi-experimental study assessing the effects of CAI and SIMs on students' academic performance based on pre-test and post-test results. Findings from this study will provide educators with evidence-based insights into selecting the most effective instructional tools, ultimately enhancing STEM learning outcomes. Furthermore, these findings will enhance biology education and support the broader objective of promoting inclusive and high-quality education, as stated in the 2030 Sustainable Development Agenda (Sustainable Development Goal 4), which was officially adopted by all United Nations Member States in 2015.

2.0 Methodology

2.1 Research Design

This research utilized a quasi-experimental approach, specifically adopting a one-group pre-test-post-test model. This design is a methodological strategy for assessing an intervention's impact without random participant assignment to experimental conditions. It typically involves pre-determined groups and relies on pre-test and post-test evaluations to analyze changes in outcomes resulting from the intervention.

2.2 Research Locale

The study occurred at Candaping National High School (CNHS) in Candaping B, Maria, Siquijor. CNHS is one of the top-performing regular schools in the DepEd Siquijor Division. It has received numerous awards for students' and teachers' academic and non-academic performance within and outside the division. The classrooms in the school are all well-ventilated and equipped with flat-screen televisions and projection screens. Its campus also has Wi-Fi connectivity for both teachers and students. The average class size in each Junior High School grade level is 35 students per section.

2.3 Research Participants

The study involved 32 grade 9 students. These students were divided into two groups or clusters, each with students who had the same level of knowledge based on their prior science grades (Grade 8 overall). The researcher employed the t-test for Independent Data, whose results showed a p-value of 0.84, greater than the significance level ($p > 0.05$). This result implies that both groups of respondents have the same performance or grades. As previously mentioned, the total population of respondents was divided into two distinct groups (clusters) based on their prior knowledge. Using a one-stage cluster sampling technique, the researcher randomly assigned an intervention tool to each group. For instance, if CAI was randomly assigned to the first group, all students in that cluster participated in the experiment under the CAI method. Similarly, the second group was assigned to SIMs, with every student in that cluster participating in the experiment under the SIMs method.

2.4 Research Instrument

The researcher developed computer-aided instructional materials incorporating interactive lessons, tutorials, simulations, and activities designed for diverse learning styles. These resources include online interactive assessments through Quizizz, educational videos from YouTube, interactive simulations using GeoGebra and JavaLab, and relevant images from Google Images. Students can access these materials via computers or other devices, enabling them to learn independently, receive instant feedback, and explore the concepts of photosynthesis and cellular respiration dynamically and engagingly.

Strategic intervention materials are printed materials that are purposefully designed resources developed by the researcher and validated by experts in the field to ensure their accuracy, relevance, and effectiveness in addressing specific learning objectives or areas of difficulty in the curriculum. The researcher created a lesson plan for incorporating CAI and SIMs into classroom discussions. The lesson plan is designed to outline the structure, objectives, activities, and assessments for a specific teaching session, allowing science teachers to provide effective instruction and facilitate student learning. Based on a specifications table, the researcher created 30-item test question sets. These test questionnaires assessed the students' performance in photosynthesis and cellular respiration. Before the final experiment, the test items were validated through expert review and underwent item analysis. Additionally, the test questions underwent a test-retest procedure, and 30 students were not included as respondents. A reliability test using Pearson's product-moment correlation yielded a result of 0.956, indicating high reliability.

2.5 Data Gathering Procedure

The process began with securing written permission from the Foundation University Graduate School. A letter of request to conduct the study was then sent to the Schools Division Superintendent of the DepEd Division of Siquijor, with an endorsement from the Foundation University Graduate School dean. Once signed and approved, the request was presented to the Candaping National High School principal and the respective Grade 9 advisers. A disclosure statement was attached to the questionnaires before their distribution to ensure the confidentiality of the students' data, inform them about the study, and secure their consent to participate.

The students' grades were obtained by first seeking permission from the school head and, subsequently, from the registrar. This step ensured that ethical protocols were observed when accessing academic records. Before the experiment and the distribution of the test questionnaires, the researcher explained the purpose and importance of the study to the students. This ensured a smooth experiment flow, with proper protocols strictly followed. The four-day experiment followed a set schedule: two hours per day for four days. The first day was spent thoroughly discussing photosynthesis and cellular respiration, which was aligned with the work budget. On the second and third days, the researcher administered CAI to one group and SIMs to the other. During these sessions, students completed activities and answered questions utilizing the CAI and SIMs. Following the activities, the researcher evaluated the students' responses and gave feedback during class discussions. On the fourth day, students received their post-test questionnaires. The collected data were then analyzed and interpreted to evaluate the students' performance in both instructional tools.

2.6 Data Analysis Procedure

The researcher utilized various statistical tools to analyze the data gathered in the study. The mean was employed to assess the students' performance in both the pre-test and post-test using CAI and SIMs. The standard deviation was used to determine the variability of students' scores, providing insights into the distribution of performance outcomes. To examine the significant difference between the pre-test and post-test scores within each group, the t-test for dependent data was applied, as the data were measured on a ratio scale. Meanwhile, the t-test for independent data was utilized to compare the post-test performances of students exposed to CAI and SIMs, ensuring an accurate evaluation of differences between the two instructional tools. Additionally, students' proficiency levels or academic performance were interpreted based on the grading criteria outlined in DepEd Order No. 8, s. 2015, providing a precise classification of their achievement levels.

2.7 Ethical Considerations

The researcher sought ethical approval from the ethical committee of the Foundation University research office to conduct the study. The respondents, who are grade 9 students at Candaping National High School, were fully aware of the study's objectives and were given the freedom to choose whether or not to participate. Lastly, confidentiality of information, such as students' grades, the data gathered during the study, and the respondents' identity, was strictly upheld.

3.0 Results and Discussion

3.1 Pre-test Performance of the Students in Photosynthesis and Cellular Respiration

Table 1 summarizes the students' pre-test scores before employing CAI and SIMs in learning photosynthesis and cellular respiration. The data reveal that the average scores for the SIMs and CAI groups were 71.92% and 71.25%, respectively, categorized as "Did Not Meet Expectations." The variability in pre-test scores is also highlighted by the standard deviations: the SIMs group had a higher SD of 5.20, indicating more diverse baseline knowledge, compared to the CAI group's SD of 4.04.

Table 1. *Pre-test Performance of the Students in Photosynthesis and Cellular Respiration*

Rating (%)	Verbal Description	CAI (n = 16)		SIMs (n = 16)	
		f	%	f	%
90 - 100	Outstanding	---	---	---	---
85 – 89	Very Satisfactory	---	---	---	---
80 – 84	Satisfactory	---	---	1	6.25
75 – 79	Fairly Satisfactory	4	25.00	5	31.25
≤ 74	Did Not Meet Expectations	12	75.00	10	62.50
Total		**16**	**100.00**	**16**	**100.0**
Mean		**71.25 (Did Not Meet Expectations)**		**71.92 (Did Not Meet Expectations**	
SD		**4.04**		**5.20**	

These findings highlight that students in both groups exhibited limited prior knowledge of the topics before the intervention. While the SIMs group demonstrated a slight initial advantage, with a greater proportion of students performing at higher levels, the CAI group had a higher concentration of students struggling to meet expectations. The low scores point to insufficient prior exposure or ineffective traditional instructional methods in building foundational understanding of these complex topics.

These results suggest that innovative, interactive teaching methods, such as CAI and SIMs, may be essential for addressing diverse learning needs. The observed variation in baseline knowledge emphasizes the need for differentiated instructional strategies. For instance, as seen in the SIMs group of students, a more heterogeneous group may benefit from scaffolding techniques or tiered activities to bridge knowledge gaps. Additionally, administering diagnostic tests before instruction can help educators identify students' specific learning gaps and design effective interventions. By understanding where students are struggling, teachers can provide support and maximize the effectiveness of instructional methods.

These findings are consistent with existing literature on students' initial understanding of complex biological concepts. For example, Mahawan and Celedonio (2023) observed that pre-test scores on bioenergetics, including topics such as photosynthesis and energy flow, often do not meet expected proficiency levels. Similarly, Kartini et al. (2021) found comparable trends in students' pre-test performance on Earth science topics, demonstrating that limited prior knowledge is a common challenge across science disciplines. Ultimately, the data emphasize the necessity of rethinking traditional instructional approaches to foster a stronger scientific conceptual foundation. Both CAI and SIMs hold promise as tools for enhancing engagement and comprehension, especially when designed to address learners' diverse needs.

3.2 Post-test Performance of the Students in Photosynthesis and Cellular Respiration

Table 2 summarizes the post-test results of students who used CAI and SIMs to study photosynthesis and cellular respiration. The CAI group achieved a "very satisfactory" performance level, with a mean percentage of 85.25%, while the SIMs group reached a "satisfactory" level, with a mean percentage of 84.24%. The differences in performance consistency are reflected in the standard deviations: the CAI group had an SD of 4.78, indicating relatively consistent scores, while the SIMs group had a higher SD of 6.70, reflecting greater variability in their results.

Table 2. *Post-test Performance of the Students in Photosynthesis and Cellular Respiration*

Rating (%)	Verbal Description	CAI (n = 16)		SIMs (n = 16)	
		f	%	f	%
90 - 100	Outstanding	3	18.75	4	25.00
85 – 89	Very Satisfactory	6	37.50	3	18.75
80 – 84	Satisfactory	5	31.25	6	37.50
75 – 79	Fairly Satisfactory	2	12.50	2	12.50
≤ 74	Did Not Meet Expectations	---	---	1	6.25
Total		**16**	**100.00**	**16**	**100.00**
Mean		**85.25 (Very Satisfactory)**		**84.24 (Satisfactory)**	
SD		**4.78**		**6.70**	

These findings highlight key trends: the CAI group not only achieved higher consistency in performance but also demonstrated the ability to transfer their understanding to authentic tasks with minimal assistance. The "very satisfactory" performance level of the CAI group suggests that technology-integrated instruction fosters autonomy and deepens mastery of complex topics. This aligns with DepEd Order No. 8, s—2015, which emphasizes achieving minimum competency standards through innovative approaches. The results show the potential of CAI to promote independent learning and enhance conceptual understanding, making it a valuable tool for teaching photosynthesis and cellular respiration. Educators may consider incorporating CAI into their teaching strategies, especially for topics requiring critical thinking and knowledge application. The interactive features of CAI, such as simulations and real-time feedback, appear to engage learners effectively, facilitating knowledge transfer to real-world contexts.

In contrast, while the SIMs group achieved satisfactory performance, the broader range of scores suggests a need for continued support to address learners' diverse cognitive abilities. Differentiated instruction, scaffolding techniques, and regular diagnostic assessments could help identify and address specific learning gaps. By designing interventions based on diagnostic data, educators can better support students needing additional guidance to improve their performance. Moreover, the observed variability in post-test results for the SIMs group highlights the importance of designing instructional materials that cater to a broader spectrum of learners. Future implementations of SIMs could be enhanced by incorporating interactive elements similar to CAI, fostering greater student engagement and understanding. These findings suggest that integrating technology-based tools like CAI, combined with the structured support offered by SIMs, can create a balanced approach to teaching complex scientific concepts. Such an approach ensures that diverse learning needs are met while promoting independent, mastery-driven learning outcomes.

3.3 Differences in the Pre-test and Post-test Performances of the Students

Table 3 highlights the comparison of pre-test and post-test performances of students using CAI and SIMs. The statistical results indicated that both groups significantly improved learning outcomes ($p < .001$). The mean score difference was higher for the CAI group (14.00) than the SIMs group (12.33), reflecting stronger performance gains among students who used CAI. These patterns emphasize the effectiveness of both tools in improving students' mastery of photosynthesis and cellular respiration, with CAI showing a particularly pronounced impact on encouraging independent learning and boosting confidence in applying knowledge.

Table 3. *Differences in the Pre-test and Post-test Performances of the Students*

Group	Pretest	Posttest	D	t	p	Decision	Remark
CAI	71.25	85.25	14.00	12.47	<.001	Reject H_{o1}	Significant
SIMs	71.92	84.25	12.33	7.80	<.001	Reject H_{o1}	Significant

t-test for dependent data at a 5% level of significance; n = 16 in each group

The findings emphasize integrating innovative instructional strategies, such as CAI and SIMs, into science education to improve student outcomes. Educators can utilize CAI's interactive features to promote autonomy and deepen conceptual understanding, while SIMs can support diverse learners, particularly in addressing specific misconceptions or gaps in knowledge. These results suggest concrete strategies for real-world teaching. First, diagnostic assessments should be conducted before instruction to identify students' baseline knowledge and plan interventions accordingly. CAI can then be employed to enhance students' engagement through simulations, animations, and real-time feedback, making it particularly effective for abstract or complex topics. Meanwhile, SIMs can be a supplemental resource to reinforce learning, especially for students needing additional guidance.

Moreover, these tools can be incorporated into blended learning environments, allowing for differentiated instruction. For instance, teachers can use CAI to provide individualized learning pathways for advanced learners, while SIMs can offer structured scaffolding for students who require more support. Regular formative assessments can help monitor progress and adjust teaching strategies to meet diverse learner needs effectively. These findings align with previous studies demonstrating the impact of CAI and SIMs on students' academic performance. Mahawan and Celedonio (2023) and Estrella (2020) observed that CAI significantly improved students' understanding of complex biological concepts, with post-test scores reflecting mastery levels. Similarly, Suarez and Casinillo (2020) and Aranda et al. (2019) reported substantial gains in students' performance after using SIMs to teach challenging science topics.

Further evidence comes from Bacatan et al. (2022) and Villaran et al. (2023), who emphasized the role of SIMs in addressing learning gaps and enhancing competencies. Parwata and Sudiatmika (2020) highlighted how instructional tools like CAI and SIMs improve problem-solving skills, creativity, and motivation across different grade levels, reinforcing the potential of these approaches in achieving academic success. The significant improvements observed in both CAI and SIM groups demonstrate the effectiveness of these tools in teaching photosynthesis and cellular respiration. These results encourage educators to adopt evidence-based practices, combining technology and strategic materials to meet diverse learning needs. Educators can create inclusive, effective science instruction that promotes deeper understanding and academic achievement by integrating diagnostic assessments, interactive CAI features, and targeted SIM interventions.

3.4 Differences in the Post-test Performances of the Students

Table 4 compares the post-test performances of students in classrooms utilizing CAI and those using SIMs. The data reveals no significant difference between the two groups, as evidenced by a p-value of 0.630, greater than the significance level. This suggests that CAI and SIMs are equally effective in enhancing students' understanding of photosynthesis and cellular respiration.

Table 4. *Differences in the Post-test Performances of the Students*

Group	Posttest	D	t	p-value	Decision	Remark
CAI	85.25	1.00	0.48	.630	Accept H_{o2}	Not significant
SIMs	84.25					

Note: t-test for independent data at 5% level of significance; n = 16 in each group

The comparable effectiveness of the two intervention tools highlights their potential to support diverse learning environments. With its interactive features, CAI provides dynamic learning opportunities, while SIMs offer structured and accessible alternatives that are less reliant on technology. Both tools address key learning objectives effectively, demonstrating their versatility in achieving desired educational outcomes. These findings hold practical implications for classroom instruction, particularly in resource-constrained settings. For schools in remote areas with limited internet access or frequent power interruptions, SIMs can serve as a viable alternative to CAI, ensuring that students still receive high-quality science instruction. Through step-by-step guidance and targeted interventions, teachers can use SIMs to introduce challenging topics, such as photosynthesis and cellular respiration.

On the other hand, schools with access to technology can maximize the benefits of CAI by incorporating animations, simulations, and interactive quizzes to engage students in active learning. Educators can also adopt a blended approach, integrating CAI for interactive exploration and SIMs for reinforcement, to provide a comprehensive learning experience adapted to students' needs. These findings align with the study by Benong et al. (2024), which reported no significant differences in learning outcomes when localized litmus paper and interactive simulations were used as interventions for teaching acids and bases in Grade 7 science. This reinforces the idea that CAI and SIMs effectively support anchored instruction, enhancing student learning by providing concrete, task-driven experiences (Kurz & Batarelo, 2005). The results of this study suggest that CAI and SIMs are comparably effective in improving students' understanding of complex scientific concepts. This equivalence allows educators to make informed decisions based on available resources, ensuring that all students can access practical instructional tools regardless of their learning environment. By applying these findings, schools can enhance science education and promote student success across diverse contexts. The result implies that the effectiveness of CAI and SIMs is comparable. The comparable post-test performance of the two groups implies that both intervention tools are equally effective in enhancing students' understanding of photosynthesis and cellular respiration.

4.0 Conclusion

The study revealed the significant impact of CAI and SIMs on student learning, particularly in complex biological processes like photosynthesis and cellular respiration. Despite initial poor performances in the pre-test, both instructional tools effectively enhanced students' academic performance, as evidenced by substantial improvements in the post-test results. These findings highlight the curriculum's dynamic nature and emphasize teachers' responsibility to adapt instructional strategies to meet the evolving needs of 21st-century learners. By integrating technology-driven and structured learning tools, educators can create more engaging and effective learning experiences that deepen understanding and retention of scientific concepts.

The findings highlight CAI and SIMs' flexibility in addressing diverse educational contexts. In resource-rich settings, CAI can incorporate multimedia elements, gamification, and interactive activities to cater to diverse learning styles and enhance engagement. Conversely, SIMs offer an equally effective option for resource-limited environments, enabling educators to deliver structured and meaningful instruction even without advanced technological infrastructure. These tools provide educators with practical solutions to teach challenging topics, such as photosynthesis and cellular respiration, while promoting active learning and inclusivity. Professional development programs should focus on equipping teachers with strategies to blend these tools into their teaching, ensuring their potential is fully realized.

While the study shows the effectiveness of CAI and SIMs, future research should explore their long-term impact on students' retention of scientific concepts and their influence on higher-order cognitive skills like critical thinking and problem-solving. Specific areas for further exploration include the comparative effectiveness of CAI and SIMs in promoting collaboration among learners, their impact on students' motivation in varying cultural contexts, and their role in supporting inclusive education for students with special needs. Additionally, research could investigate how a blended approach, combining both tools, might enhance overall student outcomes and address gaps in learning across diverse populations.

By embracing these instructional innovations, science education can become more inclusive, dynamic, and results-oriented, improving students' academic achievement, critical thinking, and problem-solving skills. These findings align with Sustainable Development Goal 4 (SDG 4) of the 2030 Agenda for Sustainable Development, which envisions universal access to quality education. Integrating CAI and SIMs helps bridge the gap between traditional teaching methods and modern educational demands, ultimately preparing learners to excel in an increasingly complex and technology-driven world.

5.0 Contributions of Authors

All authors contributed equally to every aspect of this research. They have thoroughly reviewed and approved the final version of this paper.

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7.0 Conflict of Interests

This study has no conflicts of interest in any form.

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