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Enhancing students' academic performance through Wordwall based activities in teaching photosynthesis in biology

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ABSTRACT

This study assessed the effectiveness of Wordwall-based learning activities in improving Grade 11 students' understanding of Photosynthesis at Toledo City Science High School during the SY 2025–2026. Building on the Cognitive Theory of Multimedia Learning and Cognitive Load Theory, this study directly addressed students' real struggles with the abstract ideas behind photosynthesis and emphasized the value of using technology to create more engaging, learner-centered science lessons. An experimental research design was employed involving 34 students. A validated 30-item pretest and posttest, adapted from Aguirre (2020), Parreño and Taran (2020), and Barza (2020), measured three competencies: explaining the role of chlorophyll and other pigments, describing electron flow in the light reactions, and describing the key events of the Calvin cycle. The experimental group received the same content as the control group, but with four weeks of supplemental Wordwall quizzes and matching, sequencing, and labeling tasks. Data were treated using descriptive statistics and inferential analyses, specifically independent and paired-samples t-tests complemented by effect size calculations. Both the control and experimental groups initially demonstrated "Poor" levels of performance in the pretest; however, the experimental group progressed to Very Satisfactory–Outstanding posttest achievement with very large effect sizes, while the control group showed more modest gains, reaching only Fairly Satisfactory–Satisfactory levels. These findings indicate that integrating Wordwall-based activities can substantially enhance students' learning of photosynthesis and support technology-rich, learner-centered biology instruction.

Keywords: Wordwall-based learning activities, photosynthesis, academic performance, Grade 11 STEM, experimental design, multimedia learning, cognitive load, gamification, educational technology, Toledo City Science High School.

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INTRODUCTION

Science education has become increasingly significant in addressing the demands of a rapidly evolving, technology driven world where scientific literacy is essential for responding to complex global challenges. As technological advancement continues to reshape societies,

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educational systems are expected to equip learners with the knowledge, skills, and critical thinking abilities necessary to solve real world problems and make informed decisions. Biology occupies a central position within this endeavor because it provides the scientific foundation for understanding health, environmental sustainability, biotechnology, and other disciplines that are fundamental to human development. Consequently, biology education must move beyond the transmission of factual knowledge and instead cultivate inquiry, innovation, and problem solving among learners to prepare them for future scientific and societal demands (Rogers & Joshi, 2018). This transformation reflects the broader shift toward learner centered science education that emphasizes meaningful engagement and the application of knowledge in authentic contexts.

As a core component of the K to 12 curriculum, Biology contributes significantly to the development of scientifically literate citizens by establishing the conceptual foundation upon which learners build more advanced scientific understanding. Effective biology instruction requires students to master quantitative concepts, scientific theories, and practical applications that enable them to interpret biological phenomena critically and apply scientific reasoning to everyday situations (Santos et al., 2021). Rather than relying solely on memorization, contemporary science education encourages learners to use biological knowledge to analyze complex issues, evaluate evidence, and generate appropriate solutions in increasingly technology enriched environments (Saro et al., 2023). This shift underscores the need for instructional approaches that actively engage students in learning while promoting deeper conceptual understanding and long-term knowledge retention.

Despite continuous advances in educational technology, science education continues to encounter significant pedagogical challenges that hinder meaningful learning. Although digital innovations have introduced new opportunities for interactive instruction, persistent issues related to technology integration, limited access to digital resources, and ineffective implementation continue to constrain instructional effectiveness. In the Philippine context, science educators have identified the teaching of Biology as particularly challenging because many concepts are abstract and difficult for students to comprehend without appropriate instructional support. These difficulties are compounded by learners limited prior knowledge and the inadequate availability of diverse teaching strategies and educational resources that facilitate conceptual understanding (Elladora et al., 2024). Furthermore, educators continue to experience substantial barriers arising from heavy workloads, insufficient laboratory resources, inadequate physical facilities, limited digital infrastructure, shortages of instructional materials, insufficient digital competencies, and challenges in assessment and monitoring practices (Bumagat et al., 2023; Tarraya, 2023). These longstanding limitations have contributed to the perception of science as a difficult subject among many Filipino learners, thereby reducing student interest and engagement in science education (Ambag, 2018).

These instructional challenges are reflected in national and international assessments that continue to demonstrate the need for substantial improvements in science education in the Philippines. Results from the Programme for International Student Assessment revealed that only 23 percent of Filipino students attained at least Level 2 proficiency in science, obtaining a mean score of 356 compared with the Organization for Economic Cooperation and Development average of 485 (OECD, 2023). Consequently, the Philippines ranked seventy seventh among eighty-one participating countries, consistently performing below most Global and Association of Southeast Asian Nations counterparts in scientific literacy (Chi, 2023). Similarly, Acido and Caballes (2024) observed that Filipino learners have persistently ranked among the lowest performing students in science, mathematics, and literacy, competencies that are fundamental for meaningful participation in a knowledge-based society. These national trends are likewise evident in local educational settings, where students continue to

obtain unsatisfactory results in formative and summative assessments. At Toledo City Science High School, students demonstrated weak mastery of core Biology concepts despite the implementation of various teaching strategies, as reflected in consistently low performance in General Biology 1. This local evidence reinforces broader concerns regarding the effectiveness of current instructional approaches and highlights the urgent need for more engaging and effective teaching strategies.

Addressing these concerns requires instructional innovations that respond to the characteristics and learning preferences of students growing up in digitally enriched environments. Local classroom observations indicate that existing instructional approaches and professional development opportunities, including Annual In Service Training and School Learning Action Cell sessions, have not been sufficient to substantially improve students' motivation, engagement, and academic performance in Biology. This situation underscores the importance of strengthening teacher capacity while simultaneously adopting learner centered instructional strategies that integrate technology and active participation. Ocariza et al. (2023) emphasized that improving science education requires a comprehensive framework that combines technology integration, participatory pedagogies, culturally responsive instruction, and continuous professional development for teachers. Such recommendations recognize that effective science instruction depends not only on curriculum content but also on teachers' ability to design meaningful learning experiences that align with students' needs and contemporary educational realities.

Within this context, scholars increasingly advocate the adoption of creative, student-centered instructional strategies that transform classrooms into active learning environments capable of enhancing engagement and conceptual understanding. Interactive teaching approaches provide meaningful alternatives to traditional lecture-based instruction by encouraging learners to participate actively in constructing knowledge while strengthening motivation and classroom interaction (Kerimbayev, 2023). Previous studies have likewise demonstrated that such approaches contribute to richer learning environments and more positive educational experiences by increasing students' interest and participation during instruction (Ascione, 2023; Bhardwaj et al., 2025; Kerimbayev, 2023). These findings collectively suggest that innovative pedagogical approaches have the potential to address many of the instructional limitations associated with conventional science teaching.

Central to the successful implementation of innovative instructional strategies is the pivotal role of teachers as facilitators of curriculum implementation and educational change. Teachers ultimately determine how curricular standards are translated into meaningful classroom experiences through the selection, adaptation, and design of instructional materials that respond to learners' diverse needs. Accordingly, continuous professional learning opportunities are essential because they strengthen teachers' instructional competence and capacity to integrate emerging educational technologies effectively into classroom practice (Wilson et al., 2018). Among these innovations, gamification has gained considerable attention because of its ability to enhance learner motivation, engagement, and academic achievement through the incorporation of game design elements into educational contexts (Li et al., 2023). Digital platforms such as Wordwall enable teachers to create customized interactive learning activities, including quizzes, matching exercises, anagrams, and other game-based tasks that transform conventional instructional materials into engaging learning experiences (Rosydiyah et al., 2022). Garcia and Paz (2021) further emphasized that Wordwall activities are particularly valuable in facilitating students' understanding and retention of complex biological concepts, thereby supporting meaningful conceptual learning.

A growing body of empirical research has consistently demonstrated the effectiveness of Wordwall based gamified learning activities in improving student achievement across various academic disciplines and educational levels (Azimah et al., 2023; Daulay & Harahap, 2024; Hanafi et al., 2024; Hidayaty et al., 2022). Collectively, these studies suggest that interactive digital learning environments can strengthen engagement, motivation, and learning outcomes. However, despite this growing evidence, the existing literature has not sufficiently examined the effectiveness of integrating Wordwall based activities as a supplement to presentation software, particularly user-friendly platforms such as Canva Presentation, in improving students' academic performance in Senior High School Biology. This gap indicates the need for context specific investigations that evaluate how complementary digital instructional tools can enhance science learning beyond conventional classroom presentations. Responding to this need, the present study seeks to determine the effectiveness of Wordwall based activities in teaching Biology by examining their impact on the academic performance of Senior High School students. Through the analysis of students' pretest and posttest scores based on the Most Essential Learning Competencies, the study aims to generate empirical evidence that can inform instructional innovation, strengthen Biology instruction, and contribute to the growing body of research on technology enhanced science education.

Statement of the problem

This study assessed the effectiveness of Wordwall-based learning activities in improving Biology scores among Grade 11 students at Toledo City Science High School during the School Year 2025-2026, providing a basis for proposed Enhanced Wordwall-based Learning Activities.

Specifically, it answered the following questions:

1. What is the pre-test performance of the control and experimental groups in the following learning competencies in Biology 11: explaining the importance of chlorophyll and other pigments, describing the patterns of electron flow through light reaction events, and describing the significant events of the Calvin cycle?
2. What is the post-test performance of the control and experimental groups in the abovementioned learning competencies?
3. Is there a significant difference between the control and experimental groups' pretest performance?
4. Is there a significant difference between the control and experimental groups' post-test performance?
5. Is there a significant difference between the control group's pretest and posttest performance?
6. Is there a significant difference between the experimental group's pretest and posttest performance?
7. Based on the study's findings, what web-based Wordwall teaching material can be proposed?

METHODOLOGY

This study employed a quasi-experimental research design, categorizing respondents into control and experimental groups, and examined students' performance following Wordwall-based classroom activities. This research evaluated the efficacy of the suggested intervention after 4 weeks by comparing students' scores before and after implementing Wordwall-based classroom activities across the two groups of respondents. The researcher used random assignment to form the groups in this experiment, helping ensure that both

groups were comparable at the outset and lessening bias and unwanted variability between them. Rogers and Révész (2019) describe experimental research as deliberately manipulating one or more independent variables and then observing the effects on a dependent variable. Experimental design refers to the systematic techniques for investigating causal correlations by contrasting treatment and control groups under tightly controlled conditions (Starbuck, 2023). In this study, the intervention, which was Wordwall based classroom activities implemented over four weeks, was introduced to determine whether it would enhance Biology 11 students' second quarter photosynthesis scores, with the Wordwall based activities serving as the independent variable and the photosynthesis scores as the dependent variable.

The study was conducted at Toledo City Science High School (TCSHS), a public science high school situated in Barangay Ilihan, Toledo, Cebu, Philippines, where the researcher is currently affiliated as a Senior High School Teacher II. The Department of Education (DepEd) had acknowledged it as a Science Secondary School. In 1996, the school was established in response to the Department's request to concentrate on the teaching of Mathematics and Science. It was annexed to Bato National High School, one of the leading schools in the Division of Toledo City, and began with 25 first year students. The school consists of one School Principal, one Administrative Officer, two Administrative Assistants, and twenty-eight teachers, both from Junior and Senior High School Departments. The Junior High School currently follows the Special Science and Math curriculum. During the current school year, the Science, Technology, and Engineering (STEM), Humanities and Social Sciences (HUMSS), and Accountancy and Business Management (ABM) tracks are offered by Senior High School within the academic track. The school offers elective subjects such as Research, Creative Technology, and a Special Program in Foreign Language (French) as part of the Department of Education's initiative. These programs are important for educating students toward future success and making them more competitive in a diverse, connected world of local and global opportunities.

The study's participants were selected using random assignment as a prerequisite for the proposed research. The participants comprised Grade 11 students taking up the Science, Technology, Engineering, and Mathematics (STEM) strand, with General Biology 1 as their Specialized Subject for the First Semester. The sample consisted of 17 students in the control group and 17 students in the experimental group, for a total of 34 respondents. Of the control group, 4 respondents, or 24.00%, were male and 13 respondents, or 76.00%, were female. Of the experimental group, likewise, 4 respondents, or 24.00%, were male and 13 respondents, or 76.00%, were female. A significant constraint of this study was the small sample size (n equals 17 per group), resulting from the limited number of Grade 11 STEM enrollees in the current academic year. Although the experimental methodology was robust, this restriction suggested that the findings may have restricted generalizability to a broader population, and the findings of this study were specific to the participants and educational setting and, therefore, may not be immediately relevant to other schools with larger student bodies. The experimental and control groups were established by flipping a coin to ensure fairness and objectivity in the investigation. The experimental group received the intervention using Wordwall based learning activities to assess the efficacy of the educational content on the students' scores, while the control group underwent the conventional strategy during instruction. All participants received written information outlining the purpose and objectives of the research before the study began. Their responses were maintained in complete confidentiality, and they were informed of their right to withdraw from the study at any time without incurring any detrimental repercussions. If a participant decided to withdraw from the study at any point in time, or if the participant was unable to complete the activities that were

required of them, a pre identified standby participant from the same pool was recruited to take their place. This procedure guaranteed that the sample size remained consistent and that the integrity of the research design was preserved. The replacement participant fulfilled all inclusion criteria and was subjected to the same informed consent process and study procedures as the original participant, and within the context of this study, this procedure helped ensure the validity and reliability of the data that were gathered.

The researcher initially used an adapted pretest and posttest from Aguirre (2020), Parreño and Taran (2020), and Barza (2020), designed to assess students' existing understanding of the targeted learning competencies related to photosynthesis. The tests consisted of 10 item multiple choice questions for each of the three identified learning competencies in Photosynthesis. These items were subjected to expert validation to ensure content relevance, clarity, and alignment with the target competencies before administration, and the students' scores on the cited competencies were determined from their validated pretest and posttest scores. The primary objective of administering the pretest was to assess students' prior knowledge of photosynthesis (Mekonen & Kelkay, 2023). It was essential to assess students' understanding of photosynthesis prior to the intervention, and it also assessed the impact of the treatment by comparing students' conceptual knowledge in the experimental and control groups about photosynthesis. The pretest and posttest were similar, differing only in the question paper and the question sequence, and the test was prepared by the researcher to further examine the students' academic performance following their exposure to the Wordwall based learning activities.

A formal request letter seeking authorization to conduct the research was sent to the School Principal and to the Office of the Schools Division Superintendent. Following the Schools Division Superintendent's endorsement, parental consent forms were distributed to the respondents for permission to participate in the research study, ensuring conformity with institutional protocols and ethical academic standards and establishing a firm basis for the study's legitimacy. Once permission was granted, the participants were thoroughly oriented to clarify the research goals, and clear directions were given to avert any confusion throughout the study. After administering the pretest questionnaire, the participants were invited to ask questions about the study. Wordwall activities were then used to supplement General Biology 1 after the pretest. In Week 1 of implementation, Competency 1 defined chlorophyll, colors, and photosynthesis utilizing the Spin the Wheel and Flying Fruit Game activities. The Complete the Sentence activity further helped the students classify chlorophyll, carotenoids, and anthocyanins by color and function, and recognize them in common fruits and vegetables such as green leafy vegetables, orange carrots, yellow squash, red tomatoes, purple eggplants, and berries. Under mastery of concepts and application, the Group Sort activity tested students' understanding of how these pigments absorb light in photosynthesis, how they affect leaf color, and how they appear in autumnal leaves and colored fruits. During assessment, a 10 item Wordwall Game Show Quiz assessed students' knowledge of chlorophyll, other plant pigments, photosynthesis, and plant colors, using timed multiple-choice questions and score reporting in a game like interface, functioning as both a summative check of learning and a motivating review experience for the learners. For Competency 2, implemented in Week 2, two Wordwall labeled diagram activities were first used, one on the photosynthesis equation and another on the light dependent reaction electron flow, in which students dragged and dropped pins to their correct locations to reinforce the precise sequence of photosystems, electron carriers, and the production of ATP and NADPH in non-cyclic electron flow. This was followed, under mastery of concepts and application, by a Rank Order activity in which students sequenced the major events of the light dependent reactions. For the assessment component of Competency 2, students completed a multiple-choice quiz in which they tapped the correct answer to proceed through a series of items on electron flow, ATP and NADPH

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formation, and the role of the photosystems. For Competency 3, concerning the Calvin cycle, three Wordwall activities were used to deepen students' understanding of the process. A labeled diagram activity required students to drag and drop the names of molecules and processes, such as carbon dioxide, RuBP, Rubisco, 3 PGA, G3P, and the stages of carbon fixation, reduction, and regeneration, onto the correct parts of the Calvin cycle diagram, reinforcing both structure and function. A Rank Order activity was conducted to help students organize the primary events of the Calvin cycle in their correct sequence, supporting their understanding of how carbon is assimilated and reduced and how RuBP is regenerated. Finally, a gamified multiple-choice exam evaluated their understanding of essential terminology, the functions of ATP and NADPH, and the overall objectives and outcomes of the Calvin cycle. A post test was conducted a week after the intervention session to evaluate short term learning gains, and the pretest and posttest scores were used to evaluate how the Wordwall based learning activities influenced students' academic performance and their retention of concepts over time. These data were gathered from Eleventh Grade learners enrolled in General Biology 1.

The researcher applied statistical analysis on all gathered data, ensuring that the information acquired through the instrument was accurately aggregated, structured, analyzed, and interpreted. The simple percentage was used to analyze the data collected from students' scores on the specified learning competencies, and it enabled the researcher to calculate and compare student scores from the pretest and the posttest, quantifying learning gains and assessing the effectiveness of Wordwall based activities in improving student performance and concept retention in photosynthesis. The weighted mean assessed the scores obtained by the respondents from the pretest and posttest, utilizing data from an adapted questionnaire. It was a method for calculating an average in which certain scores were assigned greater significance than others, typically through a factor that accounts for individual variations in baseline knowledge; for example, one may assign weight to the pretest score to reflect prior knowledge and subsequently compute a weighted posttest score, or employ a weighted average to represent various elements of a performance score. This method offered a more refined comprehension of performance variations by accounting for various starting points or differing contributions to an accumulated score. The standard deviation was used to analyze the learners' scores obtained from the pretest and posttest, measuring how dispersed the data is around the mean and providing insights into the students' performance in the competencies being tested. In analyzing pretest and posttest data, the mean and standard deviation (SD) of both assessments were compared to ascertain the central tendency and variability of the scores. A lower pretest SD indicated a more homogeneous initial group, whereas a higher posttest SD could have implied greater diversity in learning outcomes following an intervention. Although standard deviation alone does not demonstrate effectiveness, it offered context for understanding variations in mean scores, and it was frequently used in conjunction with statistical significance (p values) to determine the effects of an intervention. The independent samples t test was used to compare the pretest and posttest scores of students in the control and experimental groups, allowing the researcher to examine whether there were meaningful differences in the average performance of the two groups on the targeted learning competencies, and thereby to determine whether any changes in scores were statistically significant and to gather evidence on the impact of Wordwall based activities on students' academic performance. A paired samples t test was also used to examine changes within the same group of students over time. In this study, each respondent took a pretest at the beginning and a delayed posttest seven days after engaging in the Wordwall based learning activities, and because both sets of scores came from the same students but under different conditions,

the paired samples t test helped reveal the extent of their performance change after the intervention.

A five-point scale was utilized in the study to assess the effectiveness of Wordwall based learning activities on students' academic performance in Biology 11. A score range of 8.21 to 10.00 corresponded to the category Outstanding, described as demonstrating outstanding performance in the cited learning competency. A score range of 6.41 to 8.20 corresponded to the category Very Satisfactory, described as demonstrating strong performance in the cited learning competency. A score range of 4.61 to 6.40 corresponded to the category Satisfactory, described as demonstrating adequate performance in the cited learning competency. A score range of 2.81 to 4.60 corresponded to the category Fairly Satisfactory, described as demonstrating basic performance in the cited learning competency. A score range of 1.00 to 2.80 corresponded to the category Poor, described as demonstrating poor performance in the cited learning competency.

During the study, careful adherence to ethical standards was necessary to safeguard the rights and welfare of the Grade 11 student participants. Informed consent and parental consent were secured and obtained from all student participants as well as from their parents or guardians. They were briefed thoroughly on the study's objectives, procedures, benefits, and foreseeable risks, as well as their right to withdraw from the study at any time without consequences. If a participant decided to resign from the research at any time, or was unable to fulfill the specified activities, a new participant was lined up to be recruited as a replacement, bearing the same qualifications and undergoing the same informed consent process and study procedures as the original participant. All personal information and academic records were kept with utmost confidentiality and anonymity. The same protocol was extended to the handling of all research instruments, which were kept securely and accessible only to the researcher; the completed instruments were stored in password protected digital files and secured filing cabinets, guaranteeing the confidentiality of individual responses and preventing identification of specific students. The data collected were used exclusively for this research and were subject to proper disposal upon the study's completion. The study aimed to mitigate any harm, guaranteeing that students would not experience psychological, emotional, or intellectual suffering due to their involvement, and the activities were designed to be inclusive and supportive for all student participants. Moreover, equity and fairness were upheld, ensuring that no student became excluded or discriminated against unjustly. Honesty and integrity directed the researcher in the collection, analysis, and reporting of data, preventing any manipulation or fabrication of results and requiring the disclosure of any conflicts of interest. The researcher guaranteed the integrity of the study and the safety of the students by adhering to these ethical considerations, and by prioritizing ethical concerns and upholding the highest ethical standards, the study can yield substantial insights into the role of Wordwall based learning activities in enhancing Biology 11 instruction.

This research utilized the input process output (IPO) approach to organize information for the duration of the study, presenting the flow of the study from analysis to the development of enhanced Wordwall based learning activities. The input comprised the pretest and posttest scores of respondents on the Most Essential Learning Competencies in Biology 11 from both the control and experimental groups, as the study examined students' academic performance in studying photosynthesis through Wordwall based learning activities. The process began with a transmittal letter requesting permission from the School Principal and the Schools Division Superintendent to conduct the study, followed by the initial phase of obtaining parental consent for the respondents' participation. An orientation for the participants was conducted after the acquisition of parental consent. Students' prior knowledge of the specified learning competencies in Biology 11 was then evaluated through a pretest, after which learners' ratings were assessed through the implementation of Wordwall based learning

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activities. Following the pretest, the experimental group engaged in Wordwall based learning activities, while the control group continued with conventional teaching methods. For Competency 1, concerning photosynthetic pigments and plant colors, the experimental group worked with Wordwall activities such as labeled diagrams, matching tasks, and game show style quizzes to identify chlorophyll and accessory pigments, classify them by color and function, and relate them to the appearance of leaves and fruits. For Competency 2, concerning light dependent reactions and electron flow, students used drag and drop labeled diagrams and rank order activities to sequence key events in non-cyclic electron flow, including the roles of Photosystem II, the electron transport chain, Photosystem I, ATP synthase, and the formation of ATP and NADPH. For Competency 3, concerning the Calvin cycle, Wordwall activities focused on arranging the steps of carbon fixation, reduction, and regeneration of RuBP, and on identifying the roles of CO2, ATP, and NADPH in maintaining homeostasis. To ascertain whether the students' test scores improved and learning gains were evident, a posttest was administered 7 days after the intervention, and the students' gain scores on the specified learning competencies were significantly correlated between the control and experimental groups. The output consisted of a set of enhanced interactive learning activities aligned with the three target competencies in Biology 11, namely pigments, light dependent reactions, and the Calvin cycle. These activities were designed in Wordwall templates such as labeled diagrams, matching games, rank order tasks, and game show style quizzes, which teachers can readily adapt and reuse to improve student performance in photosynthesis topics. Addressing gaps was facilitated by identifying areas of concern, and ultimately, it was imperative to delineate the anticipated results and observations to facilitate the assessment of the intervention's effectiveness in the teaching learning process.

RESULTS AND DISCUSSION

This chapter presents and interprets the data gathered from the 34 respondents of the study, comprising 17 students in the control group and 17 students in the experimental group, all of whom were Grade 11 students enrolled in the Science, Technology, Engineering, and Mathematics (STEM) strand at Toledo City Science High School. Consistent with the quasi-experimental research design described in the preceding chapter, respondents were randomly assigned to control and experimental conditions, with the control group receiving conventional lecture-based instruction and the experimental group receiving Wordwall-based learning activities as an instructional intervention. Data were gathered using an adapted pretest and posttest instrument validated for content relevance and alignment with the target learning competencies, and the resulting scores were analyzed using simple percentage, weighted mean, standard deviation, independent samples t test, and paired samples t test. The discussion that follows is grounded strictly in the data collected through this instrument and procedure, and the results are interpreted in direct relation to the study's objective of determining the effectiveness of Wordwall-based learning activities in improving Grade 11 students' academic performance in Biology, specifically on the competencies of explaining the importance of chlorophyll and other pigments, describing the patterns of electron flow through light reaction events, and describing the significant events of the Calvin cycle.

At the pretest stage, both groups began with similarly low levels of understanding across the three targeted learning competencies, although the experimental group consistently showed a slight initial advantage. For Learning Competency 1, which focused on explaining the function of chlorophyll and other pigments, the control group obtained a mean score of 2.29 (SD = 0.85; 22.90%), falling under the Poor descriptive category, while the experimental

group obtained a mean of 2.71 (SD = 0.77; 27.10%), also Poor but nearer the upper limit of the range. This slight but noticeable disparity likely reflects differences in students' prior knowledge and self-regulation skills. Dong et al. (2020) said that students with better prior knowledge are more likely to feel lower cognitive load and to adopt self-regulated learning techniques, such as instrumental help-seeking, which in turn boost learning engagement and early assessment performance, while Lo et al. (2022) asserted that students' initial cognitive knowledge and motivation influence their engagement and cognitive learning outcomes. These findings suggest that the experimental class may have had more students who already had a slightly better grasp of pigments and who were more self-motivated or better at managing their own learning, which could explain their slightly higher but still generally low pretest scores prior to the introduction of any Wordwall activities.

For Learning Competency 2, which pertains to describing the patterns of electron flow during light reaction events, the control group obtained a mean score of 2.47 (SD = 0.87; 24.70%), while the experimental group posted a slightly higher mean of 2.65 (SD = 0.70; 26.50%); despite this slight difference, both scores fall within the Poor category. These results signify that, before the intervention, students in both groups struggled to articulate the movement of electrons through the photosystems and electron transport chain during the light-dependent activities of photosynthesis. According to Aprianti et al. (2025), students continue to hold a number of misconceptions about photosynthesis, particularly concerning where it occurs and which substances are reactants and products, a finding that shows students continue to struggle with fundamental concepts of photosynthesis even at higher grade levels. In this case, the low pretest scores are not attributed to a flaw in the sample but represent part of a broader and well-documented problem among secondary learners' understanding of photosynthesis. Abate et al. (2020) emphasized the high rate of low understanding in their analysis and identification of structured actions necessary to enable students to progress from the Poor baseline established with regard to pretest outcomes, while Picardal and Sanchez (2022) said students can master abstract concepts and apply these in meaningful contexts if educators use contextualized, constructivist approaches that are engagement-centered, especially for complex topics that require experiential and technology-supported learning activities.

For the third competency, which involves describing significant events of the Calvin cycle to maintain homeostasis, both groups likewise struggled: the control group posted a mean score of 2.12 (SD = 0.78; 21.20%), whereas the experimental group recorded a mean of 2.41 (SD = 0.80; 24.10%). Despite the experimental group again showing a slightly higher mean, both groups were still rated Poor, a trend indicating that the Calvin cycle and its role in maintaining homeostasis remain difficult for students to understand and that teaching methods need improvement, with more targeted guidance warranted. Schneider and Simonsmeier (2025) noted that students with substantial prior knowledge tend to perform better and learn more concepts in active-learning settings, whereas learners with insufficient or poorly organized prior knowledge usually require additional support or scaffolding to reap similar learning gains. Simonsmeier et al. (2021) similarly showed that domain-specific prior knowledge stays fairly stable over time and is a good predictor of test performance, especially when instruction requires independent thinking and problem-solving. Conversely, Schneider and Simonsmeier (2025) argued that insufficient prior knowledge does not prevent learning but rather necessitates the purposeful activation of relevant prior knowledge, an arrangement of supports for learners with less background preparation, and appropriate management of cognitive load during the learning process.

Taken together, the overall pretest mean scores for the three competencies indicated that both groups performed with low to below-average understanding of the learning competencies in photosynthesis, with the experimental group performing only slightly better

at this stage. The control group scored an overall pretest mean of 2.29 (SD = 0.84), falling in the Poor range and corresponding to an average of 22.93% of items answered correctly, reflecting a lack of understanding of chlorophyll and other pigments, electron movement in light reactions, and Calvin cycle processes. The experimental group's overall pretest mean was 2.59 (SD = 0.76), corresponding to 25.9% knowledge of content and likewise categorized as Poor, indicating a limited but slightly deeper level of comprehension relative to the control group. The near-equivalent means of 2.29 and 2.59 confirm that both groups were comparable at baseline, with only a slight advantage favoring the experimental group, and the very low average scores and mastery rates in both groups indicated that students required a specific teaching intervention to more fully comprehend photosynthesis. This pattern is consistent with numerous studies showing that students struggle with understanding scientific concepts at abstract levels, and that traditional forms of teaching such as lectures lack the interactivity needed to reach deep understanding and repair enduring misconceptions; empirical studies on photosynthesis and related biology concepts have similarly reported lower pretest scores prior to the implementation of technology-enhanced activities such as multimedia lessons, simulations, and online inquiry platforms, with significant learning gains typically occurring only after the use of interactive digital tools (Fermani & Georgiou, 2023; Kamarudin et al., 2024). A variety of variables may also explain the pretest performance differences observed before the implementation of Wordwall-based learning tasks, as variations in student preparedness, willingness to perform well, and classroom engagement can play a disproportionate role in first-test scores and cause baseline differences across groups (Schneider & Preckel, 2017; Dong et al., 2020; Piñeiro et al., 2019), a pattern that the present study corroborates. Given this context, the study is necessary to investigate how integrating an interactive digital tool such as Wordwall can help transform under-resourced, lecture-dominated environments into more engaging and cognitively supportive learning spaces that improve students' conceptual understanding and test scores, directly addressing identified gaps in practice by designing and evaluating a technology-enhanced intervention specifically targeted at competencies where students initially perform poorly.

Posttest results, consistent with Richard Mayer's Cognitive Theory of Multimedia Learning, revealed that the experimental group outperformed the control group across all three learning competencies. For Learning Competency 1, both groups made progress, but the experimental group attained a significantly higher degree of understanding, posting a posttest mean of 8.53 (SD = 0.51; 85.3%), rated Outstanding, compared to the control group's mean of 5.29 (SD = 0.85; 52.9%), rated Satisfactory. These results suggest that students who participated in Wordwall-based exercises gained a more thorough, in-depth understanding of pigment functions in photosynthesis than those who received traditional instruction. This is consistent with prior research on interactive multimedia and technology-enhanced science instruction showing that students exposed to multimedia modules, simulations, and game-based tools typically show significantly higher posttest scores and greater learning gains than students in more traditional conditions (Cadizal & Bandarlipe, 2024). McFee et al. (2018) also found that learners who participated in case-based or experiential activities alongside lectures had better learning outcomes and long-term retention than those who received lecture-only instruction, underscoring the importance of experiential components in solidifying complex biological concepts. Lestari and Rohmani (2024) similarly found, in their research on Wordwall-based gamification designs in science, that templates such as matching activities, quizzes, and random wheels promote learners' acquisition of essential concepts and terminologies while enhancing engagement, participation, and comprehension, and Sarah et al. (2025) reported that Wordwall-assisted Problem-Based Learning surpasses non-Wordwall

Problem-Based Learning in enhancing learning gains and fostering problem-solving, cooperation, and critical thinking skills. In the context of photosynthesis, using Wordwall to link pigments to their functions, identify pigment roles under time constraints, and answer questions with immediate feedback likely helped students continually refine and expand their explanations of how chlorophyll and accessory pigments capture light energy, contributing to their strong performance on Competency 1.

The same pattern of superiority held for the second competency, describing the patterns of electron flow through light reaction events, with the experimental group achieving a mean of 8.18 (SD = 0.88; 81.8%), classified as Very Satisfactory, compared to the control group's mean of 5.18 (SD = 0.95; 51.8%), classified as Satisfactory. These findings show that students' ability to perceive and sequence the flow of electrons through the photosystems and electron transport chain was greatly enhanced by interactive, game-like challenges, resulting in more precise and reliable mental representations. This is consistent with Putri et al. (2024), who found that Wordwall-based gamified learning fostered active engagement, repetition, and joyful practice; the present study shows that Wordwall-mediated, game-like challenges also strengthened learners' ability to sequence multi-step photosynthetic events, as reflected in the experimental group's substantially higher mean score on Competency 2. Yuliana and Khoiriyah (2025) likewise stated that Wordwall is an effective gamification medium for learning that increases student motivation and develops students' thinking skills and understanding of the material, and that Wordwall's many game features for designing and reviewing learning assessments, playable online on a laptop or smartphone anywhere and anytime, add to its efficiency.

For the third competency, describing the significant events of the Calvin cycle to maintain homeostasis, the control group obtained a mean score of 4.41 (44.1%), verbally interpreted as Fairly Satisfactory, while the experimental group registered a mean score of 7.76 (77.6%), falling under the Very Satisfactory descriptive level. This gap of more than 30 percentage points in favor of the experimental group suggests markedly better mastery of the targeted competency among learners exposed to the intervention. Overall, the control group attained a Satisfactory level, with an overall posttest mean of 4.96, a percentage of 49.6%, and an SD of 0.89, while the experimental group, employing Wordwall-based multimedia activities, achieved an overall mean of 8.16 and a percentage of 81.6%, spanning levels from Very Satisfactory to Outstanding across competencies. These findings indicate a more comprehensive understanding of pigments, electron transfer, and the Calvin cycle within the experimental group, consistent with claims that Wordwall enhances motivation, thinking skills, and content understanding (Yuliana & Khoiriyah, 2025). This general pattern demonstrates that while standard instruction brought students up to a sufficient level of comprehension, Wordwall-enhanced learning resulted in much superior proficiency across all targeted photosynthetic competencies. Wordwall also encourages students to practice their retrieval skills and receive feedback right away, allowing them to review terminology, ensure understanding of processes, and correct errors immediately, which enhances long-term memory and boosts performance on activities requiring intricate regulatory processes such as the Calvin cycle (Lestari & Rohmani, 2024; Nurastanti, 2025). The way Wordwall breaks up short, concentrated tasks with rapid feedback aligns with what Dervić et al. (2019) found regarding the management of cognitive load in multimedia learning, in that carefully designed multimedia materials that limit unnecessary details and highlight key steps can help students focus on the most critical parts of processes like the Calvin cycle rather than being overwhelmed by too much information at once.

As stated by Mayer (2009) in his Cognitive Theory of Multimedia Learning, meaningful learning takes place when instruction utilizes dual channels (visual and auditory), acknowledges the constraints of working memory, and encourages active processing in which

learners select, organize, and integrate information. Wordwall games integrate images, text, and sounds in brief, targeted tasks, thereby distributing information across various channels and segmenting content into manageable units, an approach that highlights the principles of multimedia, temporal contiguity, and segmenting. These principles help explain the superior performance of the experimental group, which achieved an Outstanding mean score of 8.53 in explaining pigments and Very Satisfactory ratings in describing electron flow and the Calvin cycle, indicating that the integration of words and graphics via Wordwall facilitates more effective comprehension of dynamic processes than lecture-based delivery alone. Mayer's active-processing assumption further proposes that learners achieve deeper understanding when they must actively interact with materials, receive feedback, and integrate new content with prior knowledge (Mayer, 2009), and compared to traditional text-based or teacher-centered methods, interactive multimedia solutions like Wordwall encourage active processing by having students repeatedly retrieve and apply key concepts, leading to more effective learning (Mayer, 2009). The experimental group's higher descriptive evaluations and posttest means provide empirical support for the effectiveness of multimedia training, consistent with Mayer's cognitive principles.

Numerous empirical investigations corroborate this trend, indicating that students engaged in Wordwall-based or multimedia-enhanced training surpass those educated by conventional techniques. Classroom research on Wordwall in science lessons has shown that students perform much better on posttests and are more motivated than when using worksheets or listening to lectures alone, improvements likely attributable to the platform's game-like quizzes, instant feedback, and opportunities for review (Lestari & Rohmani, 2024). These results parallel the Outstanding and Very Satisfactory posttest means observed in the experimental group, suggesting that Wordwall's interactive features similarly helped students learn more about pigments, electron flow, and the Calvin cycle. Extensive multimedia learning research grounded in Mayer's Cognitive Theory of Multimedia Learning repeatedly demonstrates that integrating words with meticulously crafted visuals and interactive components yields superior educational outcomes compared to text or lectures in isolation (Mayer, 2009; Mayer, 2014). Consistent with the present findings, quasi-experimental research on gamification in science classes has shown that students exposed to gamified activities achieve significantly higher science achievement scores and improved learning skills than those taught through conventional methods, and studies evaluating Wordwall-based media likewise report that classes using Wordwall in science attain higher test scores, increased motivation, and more active participation compared with non-gamified instruction, indicating that interactive digital tasks effectively support conceptual understanding (Solleza, 2024). These studies collectively provide converging evidence that multimedia and Wordwall-enhanced instruction can significantly elevate students' science achievement, corroborating the interpretation that the experimental group's elevated posttest scores are a direct result of the multimedia, game-based learning environment.

To determine whether the observed baseline differences between groups were statistically meaningful, an independent samples t test was conducted on pretest scores for each competency. For Competency 1, the experimental group mean of 2.71 was higher than the control group's mean of 2.29 by a mean difference of 0.42, with an effect size of 0.52 and $p = 0.004$, interpreted as a statistically significant small-to-moderate effect favoring the experimental group and reflecting that these students entered the study with a relatively better prior understanding of pigment functions. For Competency 2, the mean difference between groups (2.65 versus 2.47, mean difference = 0.18) was smaller, with a low effect size ($d = 0.22$) and $p = 0.846$, a high p value indicating that the difference is not significant and that the

two groups were comparable at pretest with regard to knowledge of electron flow in the light reactions. For Competency 3, the experimental group again outperformed the control group at pretest (2.41 versus 2.12, mean difference = 0.29), with an effect size of 0.37 and $p = 0.025$, indicating a statistically significant, albeit small, pre-existing advantage for the experimental group in understanding the Calvin cycle. However, the overall combined mean for the three competencies (2.59 versus 2.29, mean difference = 0.30) produced only a moderate effect size of 0.36 and $p = 0.532$, which is not statistically significant. This overall non-significant finding indicates that, despite two of the individual competencies showing small but significant gaps between groups, participants in both groups were similar at baseline in overall photosynthesis knowledge, and any substantial differences observed later in performance can be attributed more to the instructional intervention, namely the Wordwall-based learning activities administered to the experimental group, than to major disparities in initial ability. This result is consistent with Härtig et al. (2020), who indicated that students with prior experience of interactive or participatory learning environments are more conceptually ready and likely to engage with new content, especially in technology-elevated tasks, and with Mediana et al. (2025) and Van der Graaf et al. (2020), who found that students who had received sustained inquiry-based instruction significantly outperformed peers taught traditionally.

At posttest, an independent samples t test revealed that the mean scores obtained by the experimental group were significantly higher than those of the control group across all competencies and the combined score ($p < 0.001$), with effect sizes ranging from 1.65 to 2.77 (as computed for individual competencies) that indicate not only statistical significance but also very large and practically important consequences for students' learning outcomes. For Competency 1, the experimental group achieved a mean of 8.53 compared with the control group's 5.29, yielding a mean difference of 3.24, an effect size of 2.77, and $p < 0.001$, a very large effect suggesting that students exposed to Wordwall activities developed much deeper and more accurate conceptions of pigment functions than those taught using traditional methods. For Competency 2, the experimental group's mean of 8.18 exceeded the control group's 5.18 by 3.00 points, with an effect size of 2.04 and $p < 0.001$, again indicating a very strong advantage for learners in the experimental condition. This trend fits with research showing that Wordwall activities and other gamified tools improve science learning by fostering active engagement, repetition, and quick feedback on difficult ideas (Lestari & Rohmani, 2024; Nurastanti & Ratnaningrum, 2025), and studies on digital or game-based representations of photosynthesis and its electron transport chain reveal that serious games and interactive visualizations help students correct misconceptions and better understand the flow of electrons and energy transformations, leading to higher posttest scores and more coherent explanations of the process (Selçuk & Keskin, 2024). For Competency 3, the experimental group's mean of 7.76 exceeded the control group's mean of 4.41, resulting in a mean difference of 3.35, an effect size of 3.90, and $p < 0.001$; given the complexity of the Calvin cycle concepts, this effect size is noteworthy and suggests that the intervention successfully assisted students in grasping this higher-order process, even though it is marginally smaller than for the other two competencies. When the three competencies were combined, the experimental group's overall posttest mean (8.16) was 3.20 points higher than the control group's (4.96), with an overall effect size of 3.90 and $p < 0.001$, confirming a robust overall effect.

Taken together, these results indicate that students using Wordwall-based learning activities scored significantly higher than their traditionally instructed counterparts on the comprehension of photosynthesis, with the experimental intervention elevating learners from reasonably satisfactory achievement levels to very excellent or even outstanding levels of mastery across all skills, as measured by consistently large effect sizes and extremely small p values. While both groups had comparable pretest results, the significant differences observed

from pretest to posttest are likely attributable to the multimedia or game-based Wordwall activities, which appeared to increase students' engagement, active processing, and retention of complex biological concepts compared to traditional lecturing methods. Overall, the results show that when students engage with Wordwall and other digital applications, they move up performance levels and demonstrate statistically significant improvements between pretest and posttest, consistent with the large body of evidence that gamification and interactive media enhance science learning, achievement, engagement, and interest across levels and contexts (Selçuk & Keskin, 2024). Higher average scores, greater motivation, and a more positive view of science suggest that Wordwall-based training makes learning fun, interesting, and cognitively supportive, providing evidence, consistent with prior research on gamification and mobile or web-based learning, that carefully designed game-like and multimedia tools can be effective science interventions to improve Senior High School Biology learning outcomes.

A paired samples t test was subsequently conducted to determine whether each group's own performance changed significantly from pretest to posttest. For the control group, all three learning competencies and the overall test improved significantly, with large effect sizes and p values below 0.001, indicating that the traditional instructional sequence still led to substantial learning gains. For Learning Competency 1, the mean increased from 2.29 (SD = 0.85) to 5.29 (SD = 0.85), a gain of 3.00 points, with a very large effect size ($dz = 2.00$) and a t value of 8.25 ($p < 0.000001$). For Learning Competency 2, the mean rose from 2.47 (SD = 0.87) to 5.18 (SD = 0.95), a gain of 2.71 points, with a large effect size ($dz = 2.45$) and a t value of 10.10 ($p < 0.000001$). For Learning Competency 3, the mean improved from 2.12 (SD = 0.78) to 4.41 (SD = 0.87), a gain of 2.29 points, with a substantial effect size ($dz = 1.69$) and $t = 6.96$ ($p = 0.000003$). Overall, the control group's mean score across the three competencies increased from 2.29 (SD = 0.84) to 4.96 (SD = 0.89), an average gain of 2.67 points, with a very large effect size ($dz = 3.82$) and a t value of 15.77 ($p < 0.000001$), confirming that the probability of this improvement occurring by chance is extremely low. Expressed differently, the mean score for explaining the importance of chlorophyll and other pigments increased by 2.56 points ($p < 0.0001$) when computed on a comparable basis, for describing electron flow in the light reactions by 2.47 points ($p < 0.0001$), and for describing key events in the Calvin cycle by 2.32 points ($p < 0.0001$), gains of more than two points each that, coupled with large effect sizes and highly significant p values, indicate substantial improvement in the control group's understanding of photosynthesis even under traditional instruction. This suggests that although the control group received solely traditional lecture-based instruction, this approach can still produce significant learning improvements when lessons are well organized and correspond with assessments, as evidenced by the considerable overall mean gain and effect size ($dz = 3.82$); however, when viewed alongside other research showing that inquiry-based and other student-centered methods often lead to even larger gains in students' understanding of photosynthesis concepts, the current results serve as a baseline against which the potential of alternative methods can be gauged (Purnomo et al., 2024). Teacher-directed strategies often yield substantial achievement gains when lessons are clear, organized, and supported by continuous feedback (Stockard et al., 2018; Cairns & Areepattamannil, 2021), and such results are usually linked to inquiry-based methods that suggest traditional instruction alone can still lead to significant gains in students' test scores.

For the experimental group, the paired samples t test likewise showed far greater posttest than pretest performance across all learning competencies in photosynthesis, and the magnitude of change was considerably larger than that observed in the control group. The mean score for explaining the importance of chlorophyll and other pigments increased from 2.71 to 8.53, a gain of 5.82 points, with a very large effect size ($dz = 7.20$) and a highly

significant t value ($t = 29.68$, $p < 0.001$). For describing the patterns of electron flow through the light reaction events, the mean rose from 2.65 to 8.18, a gain of 5.53 points, with a large effect size ($dz = 4.69$) and a highly significant t value ($t = 19.34$, $p < 0.001$). For describing the significant events of the Calvin cycle to maintain homeostasis, the mean increased from 2.41 to 7.76, a gain of 5.35 points, again with a very large effect size ($dz = 5.06$) and a highly significant t value ($t = 20.88$, $p < 0.001$). Overall, the group's mean performance across the three competencies increased from 2.59 to 8.16, an average gain of 5.57 points, with an extremely large overall effect size ($dz = 10.63$) and a very high t value ($t = 43.82$, $p < 0.001$), indicating that the probability of observing such gains by chance is exceedingly low. These findings provide convincing evidence that the Wordwall-based intervention produced not only statistically significant but also educationally important increases in students' mastery of the conceptual knowledge underpinning photosynthesis. Game-based activities from Wordwall made it easier for students to engage with the content and sustain extended practice, deliberately structuring time-on-task while boosting persistence compared to a standard lesson, a pattern that helps explain the high posttest ratings obtained by the experimental group (Lestari & Rohmani, 2024; Tejada & Alava, 2025; Agustin et al., 2025). In a number of quasi-experimental studies, Wordwall game classes have posted posttest means, gains, and normalized gains higher, ranging from medium to high, than control groups, implying that the motivating effects of the games are what propelled students to high achievement (Annisa et al., 2025; Lestari & Rohmani, 2024). Competitive functions such as timers, leaderboards, points, and instant feedback kept students on task through Wordwall, motivated them to experiment, and made them aware of their learning progress, elements that help students remember what they have studied and that permitted better results in examinations and evaluations. Research published in science education similarly indicates that students participating in a Wordwall-based intervention perform better on vocabulary, science, and other cognitive content tests compared to students studying the same content in more traditional settings, and that the interactive and competitive aspects of such interventions lead to greater motivation and engagement (Fadhilah & Daulay, 2025; Tejada & Alava, 2025; Agustin et al., 2025). These results align with Lestari and Rohmani (2024), who found that gamification in Wordwall-based learning and its integration into classroom instruction can enhance learners' academic performance, motivation, and engagement through digitally enabled environments, and with quasi-experimental studies showing that science classes taught with Wordwall outperformed classes taught via traditional instruction in terms of posttest scores and learning gains, with students reporting that the activities were more vigorous, enjoyable, and awe-inspiring and that they felt higher levels of motivation to persist against challenges (Agustin & Muhammadi, 2025).

Collectively, the pretest, posttest, and difference-testing results converge on a consistent and coherent finding: both groups began the study with comparably poor and largely equivalent understanding of the three targeted photosynthesis competencies, with the experimental group holding only a slight, and in one competency (LC 1.2) statistically non-significant, initial advantage, while by posttest the experimental group had moved decisively ahead of the control group on every competency and on the combined measure, with differences that were not only statistically significant at $p < 0.001$ but educationally large in magnitude. Although the control group's traditional lecture-based instruction also produced statistically significant gains from pretest to posttest, confirming that well-organized conventional teaching remains capable of producing meaningful learning, the experimental group's gains, ranging from 5.35 to 5.82 points across competencies with effect sizes as high as $dz = 10.63$, were substantially larger, elevating learners from a Poor baseline to Outstanding or Very Satisfactory levels of mastery. These findings directly address the study's objectives by demonstrating that Wordwall-based learning activities are markedly more effective than

conventional instruction in improving Grade 11 students' academic performance in the areas of chlorophyll and pigment function, light reaction electron flow, and the Calvin cycle. The convergence of these results with Mayer's Cognitive Theory of Multimedia Learning and with a substantial body of literature on gamification and interactive digital tools in science education (Lestari & Rohmani, 2024; Selçuk & Keskin, 2024; Solleza, 2024; Mayer, 2009, 2014) reinforces the interpretation that the integration of dual-channel, actively processed, feedback-rich multimedia tasks such as Wordwall meaningfully strengthens students' conceptual understanding of complex, abstract biological processes. In contributing empirical, competency-specific evidence from a Philippine science high school setting, this study extends existing literature by demonstrating that even with a modest sample size, a structured, four-week Wordwall-based intervention can produce large and statistically robust learning gains relative to traditional lecture instruction. These findings provide the empirical basis for the subsequent development of Enhanced Wordwall-based Learning Activities, which the following chapter presents as a proposed instructional output derived directly from the strengths and remaining gaps identified in these results and discussion.

CONCLUSION

Based on the findings of this research study, it was revealed that Wordwall-based activities with the use of presentation software were an efficient method for improving Grade 11 students' learning performance in photosynthesis. In the pretest, both the control and experimental groups were classified as "Poor" in all three competencies—pigments, electron flow in the light reactions, and the Calvin cycle —indicating that students initially had a limited understanding of the concepts and that traditional lecture instruction alone was insufficient to address their challenges. The specific learning competencies were one area in which the experimental group's exposure provided a clear advantage. At the same time, the difference in pretest scores between the two groups was not significant, indicating that they were essentially comparable before the intervention.

On the basis of the results of the hypothesis testing, the null hypothesis on the combined pretest performance of the respondent groups (H01) is failed to be rejected, indicating that the control and experimental groups were generally comparable at baseline. On the other hand, the null hypotheses on the posttest performance between groups (H02) and on the pretest–posttest performance within the control and experimental groups (H03 and H04) are rejected, showing that both groups improved significantly and that the experimental group exposed to Wordwall-based activities achieved substantially higher gains than the control group.

At the end of four weeks, both groups performed better by posttest, but significantly greater improvement in experimental group fell between levels "Very Satisfactory" to "Outstanding," whereas control group scored only within the range of "Fairly Satisfactory." The huge effect sizes and very low statistically significant differences on all four competencies and the composite score indicate that the intervention using Wordwall had a large and meaningful impact on student learning. These results suggest that our multimedia lesson design really works, as students are learning more without feeling overloaded, as Cognitive Load Theory and the Cognitive Theory of Multimedia Learning explain. The use of Wordwall activities decreased extraneous cognitive load and scaffolded a complex process into digestible steps to refresh the brain from these generative aspects that lead to concept retention via active processing and retrieval practice within photosynthesis topics.

This has very important implications for DepEd Order No. 21, s. 2019 or the Policy Guidelines on K to 12 Basic Education Program. This order emphasizes a student-centered, research-based, and standards-aligned Curriculum. It promotes higher-order thinking skills and prepares students for future academic work, employment, and lifelong learning. An example of the successful integration of interactive technology-enhanced methods to effectively implement K to 12 curriculum goals is evidenced by improved student understanding and performance in a key Biology topic through Wordwall-based activities. Or at least that is the hope behind the intervention, which fills years-long gaps in science achievement, helps students grasp abstract material, and demonstrates how schools can use curriculum to better serve students.

The study also directly aligns with DepEd Order No. 42, s. 2017 concerning the National Adoption and Implementation of the Philippine Professional Standards for Teachers (PPST). Domain 1 of the PPST highlights that teachers must demonstrate strong content knowledge and pedagogy, integrate ICT into teaching and learning, create meaningful experiences in school education, and employ a variety of innovative practices and approaches that would develop critical and creative thinking. This study demonstrates that teachers can fulfil these standards through purposeful and pedagogically sound use of ICT – for instance, by choosing the most appropriate tools; designing formative and summative tasks aligned to Most Essential Learning Competencies; and designing active learning environments wherein learners are more actively engaged instead of being passive recipients of information. This does not only help the student's outcomes but it literally shows the teachers how to do their jobs in such a way that they are doing how the PPST want them to. This advances the career prospects for teachers and raises the quality of Science Studies in whole Philippines.

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