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| RESEARCH ARTICLE

Computer-Aided Instruction Vis-à-vis Academic Achievement of Grade 12 Students

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| ABSTRACT

This study evaluated the effect of Computer-Aided Instruction (CAI) on the academic achievement of Grade 12 STEM students in Empowerment Technologies at Pardo National High School during the 2025–2026 school year. Using a quasi-experimental, non-equivalent control group design, the study involved two intact groups of 52 students, divided into an experimental group taught via CAI modules and a control group taught through traditional instruction. Data were gathered using a localized 40-item test that was validated and pilot-tested, yielding a Cronbach's alpha reliability coefficient of 0.8721. Statistical analysis was conducted using frequency counts, percentage distributions, paired-samples t-tests, and independent-samples t-tests. The findings revealed no significant difference between the pretest performances of the two groups, indicating that the two groups had comparable baseline knowledge before the intervention. Following the instructional period, both groups achieved very good academic performance on the post-test. Furthermore, a significant difference was observed between the pretest and post-test performances within both the control and experimental groups, indicating that both instructional methods were associated with significant academic growth. However, statistical analysis indicated no significant difference between the final post-test performances of the two groups, demonstrating that while CAI successfully facilitated learning, it yielded comparable academic achievement outcomes to traditional instruction. Based on these findings, it is concluded that custom-designed CAI serves as a highly viable pedagogical alternative that matches the efficacy of conventional methods while managing cognitive load and fostering independent learning tracking. The study recommends that public secondary educators strategically deploy contextualized digital instructional modules to complement classroom instruction and accommodate diverse learning paces within the STEM curriculum.

| KEYWORDS

Computer-Aided Instruction, Empowerment Technologies, Academic Achievement, STEM, Quasi-Experimental, Philippines

| ARTICLE INFORMATION

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1. Introduction

In the contemporary educational landscape, technology plays a pivotal role in driving instructional transformation. As a foundational element of Computer-Aided Instruction (CAI), dynamic digital media transforms the delivery, cognitive processing, and retention of instructional content. By introducing unprecedented levels of interactivity, personalization, and multimedia integration, CAI offers pedagogical advantages that customary, lecture-based instructions cannot easily replicate. International research has established a robust baseline regarding the efficacy of CAI in optimizing academic outcomes. For instance, Sulaiman et al. (2010) demonstrated through a rigorous meta-analysis that CAI significantly enhances student performance in highly structured subjects like mathematics, particularly when interactive software and multimedia elements are deeply integrated into the daily curriculum. Building upon this global baseline, contemporary researchers place heavy emphasis on the cognitive mechanisms driving this success. Alammary et al. (2014) highlighted that advanced e-learning systems operating on CAI principles facilitate deeper conceptual understanding and long-term knowledge retention. This optimization occurs because digital modules allow learners to progress at an individualized pace while receiving instantaneous, automated formative feedback.

Within the Philippine public education system, localized literature confirms that technology-enhanced instruction yields comparable academic success. Tamayo-Urbina and Dalayap (2025) empirically demonstrated that Filipino high school students utilizing specialized electronic learning systems achieved significantly higher academic performance milestones than cohorts subjected purely to conventional, teacher-led lecture delivery. This instructional efficacy is similarly evident within the technical-vocational and skills-based components of the national curriculum. Conejo et al. (2025) found that video tutorial-based CAI modules significantly improved student comprehension and classroom participation in localized Technology and Livelihood Education (TLE) lessons. Furthermore, local researchers observe that CAI serves as an excellent equalizer in congested public educational settings. Goroleo (2024) emphasized that localized CAI frameworks seamlessly accommodate diverse learning styles by granting students the autonomy to review complex technical lessons repeatedly at their own pace—a critical operational feature for managing mixed-ability classrooms.

Beyond basic technical skill acquisition, CAI is documented to exert a strong affective impact on the Filipino learner. Panga et al. (2025) reported that integrating CAI mechanisms drives a noticeable increase in learner motivation, emotional engagement, and overall focus during the instructional period. At the tertiary and materials-development level, research indicates that the key to maximizing these dual cognitive and affective benefits lies in contextualization. Marquez (2017) developed and validated localized CAI software for college statistics, demonstrating that custom-built, locally designed CAI resources perfectly align with prescribed institutional learning objectives while systematically demystifying highly abstract technical concepts for students.

The Literature Gap: Despite this growing body of international and local literature, a critical empirical gap remains. Existing studies have predominantly focused on basic mathematics, lower secondary education, or fundamental technical-vocational skills, leaving a distinct empirical void regarding how CAI impacts highly specialized Senior High School (SHS) tracks. Specifically, there is a lack of localized data concerning the efficacy of CAI within the *Empowerment Technologies* curriculum for Grade 12 Science, Technology, Engineering, and Mathematics (STEM) students—learners who uniquely require advanced, self-paced digital mastery as they transition into a highly digitized workforce. Furthermore, because previous local literature primarily celebrates successful interventions that yield significant performance gains, a secondary empirical gap exists in analyzing cases where CAI produces academic achievement comparable to traditional teaching. This emphasis has overlooked how custom modules manage cognitive load and maintain user acceptance even when raw test scores are comparable.

Objectives of the Study: To address these considerations, this study evaluates the effectiveness of Computer-Aided Instruction in Empowerment Technologies among Grade 12 STEM students at Pardo National High School. By examining this specific intervention, the study addresses a localized gap in the literature and provides evidence-based frameworks for secondary educators integrating 21st-century instructional technologies.

2. Literature Review

This study is grounded in Piaget's (1936) Constructivist Learning Theory, which asserts that knowledge is actively constructed by the learner through direct environmental engagement and experiential discovery. Applied to Computer-Aided Instruction (CAI), this framework positions students as active agents who construct meaning through interactive digital tools. By leveraging interactive digital simulations and self-paced instructional modules, students can test hypotheses, navigate complex problem sets, and immediately reflect upon their operational outcomes. When applied to highly technical domains, constructivism explains how digital architecture prompts holistic cognitive, affective, and psychomotor development through a systematic synthesis of multimedia resources. This technological evolution transforms the traditional instructional interface into an active, learner-centered sandbox where students manipulate digital variables to discover underlying computational rules (Bruner, 2003).

Recent scholarship underscores the empirical value of grounding contemporary digital tools within this active learning framework. When designed around constructivist principles, modern digital learning environments foster advanced problem-solving skills and deeper conceptual understanding. This approach creates a collaborative ecosystem where students actively construct knowledge through dialogue and shared digital workspaces (Kudin et al., 2023). By situating the learning process within an authentic, multimedia-rich context, CAI operationalizes the active engagement and contextual learning long championed by constructivist pioneers. This is particularly evident in a technical subject like Empowerment Technologies, where Grade 12 students cannot simply memorize theories of digital communication. Instead, they must actively construct concrete digital artifacts—such as websites and collaborative presentations—which serve as externalized, measurable representations of internal cognitive growth (Hedegaard, 1998).

While constructivism explains how knowledge is actively built, Cognitive Load Theory (CLT) serves as a critical counter-balance by explaining the structural efficiency of instructional design. Originally developed by Sweller (1988), elaborated by Sweller and Chandler (1991), and later expanded by Paas et al. (2003), CLT details the strict constraints of human working memory. The theory demonstrates that even the most innovative CAI module will fail if its interface design imposes an excessive, extraneous load on the student. Human cognitive architecture features a highly finite working memory capacity that is easily overloaded by complex or poorly formatted content, alongside an expansive long-term memory where complex knowledge structures, or schemas, are permanently stored. For technical subjects like Empowerment Technologies, which carry a high intrinsic cognitive load due to complex coding, image manipulation, and data analysis workflows, CAI design must be carefully optimized. The digital presentation should strategically manage germane processing to foster schema automation within the learner's cognitive architecture (Sweller, 2011). Modern empirical evidence establishes that structured pacing within CAI is a cognitive necessity rather than a mere convenience. Contemporary studies confirm that adaptive pacing and the systematic segmentation of complex tasks prevent working memory overload. By carefully balancing visual and textual information, CAI eliminates the "redundancy effect," which occurs when identical information is presented in two different modes simultaneously—such as displaying on-screen text alongside a verbatim narration—thereby freeing vital cognitive resources for deeper conceptual mastery (Wijekumar, 2024; Poupard et al., 2025). Instructional sequencing plays a pivotal role in CAI efficacy. In digital learning settings, multimedia designs that balance visual and auditory channels mitigate cognitive overload, enhancing technical comprehension across diverse student cohorts (Liu, 2024). Conversely, poorly structured media overburden working memory. By systematically managing intrinsic and extraneous loads, optimized CAI facilitates a seamless transition from novice to expert understanding. To fully explain the psychological factors driving student interaction with these optimized interfaces, this study integrates the Technology Acceptance Model (TAM). Introduced by Davis (1989), TAM identifies perceived usefulness (PU) and perceived ease of use (PEOU) as the two primary determinants of a user's behavioral intention to utilize a specific system. TAM posits that these primary internal beliefs accurately predict an individual's attitude toward technology, which subsequently dictates actual usage behavior. In the specific educational landscape of Grade 12 Empowerment Technologies, a student's academic performance is inextricably linked to their psychological readiness to engage with digital tools. A positive attitude toward an instructional platform may support the sustained interaction required for learning. Even a perfectly designed CAI module that carefully manages cognitive load will remain underutilized if students find the interface cumbersome or fail to see its direct value to their future professional careers (Aburayya et al., 2023).

Applied to public education, TAM indicates that behavioral intention to adopt technology is driven primarily by perceived performance gains relative to ease of mastery (Ul Haq et al., 2025). While TAM relies heavily on these two core cognitive beliefs, it explicitly accommodates external variables—such as computer self-efficacy, social influence, and facilitating conditions—as antecedents that shape those perceptions. Consequently, robust institutional support and positive peer encouragement serve as external factors that elevate students' perceptions of a tool's utility and ease of use, ultimately driving higher engagement and academic achievement. Similarly, when students view a CAI resource as an intuitive tool that makes learning efficient or helps them master industry-standard software, their motivation increases, creating a positive feedback loop that enhances performance (Varga & Napoles, 2025), this correlation between user acceptance and motivation has been repeatedly verified, showing that TAM constructs significantly predict a student's intention to interact with digital platforms. Ultimately, the successful intersection of engaging design, managed cognitive load, and high user acceptance yields the most significant improvements in overall learner performance.

I. Computer-Aided Instruction and Modern Literacy

Computer-Aided Instruction (CAI) is widely defined as a dynamic instructional modality that leverages interactive software, allowing learners to master complex technical concepts at a self-directed pace. Contemporary digital literacy theories posit that conventional lecture delivery frequently leads to student cognitive disengagement. Conversely, multimedia learning literature establishes that computer-aided instruction functions as an adaptive tutorial system—providing real-time feedback, segmenting complex technical tasks, and stimulating dual cognitive channels. Synthesizing dynamic graphics, text, and interactive simulations enables CAI to optimize working memory capacity and facilitate complex schema acquisition (Mayer, 2013). In the localized context of the Philippine basic education system, the Department of Education (DepEd) structures "Empowerment Technologies" as a specialized core subject designed to equip senior high school students with foundational 21st-century ICT skills. Official curriculum frameworks emphasize that this subject goes beyond basic computer literacy; it demands that students actively navigate online safety, evaluate rich user experiences, and master complex digital architectures like Web 2.0 and Web 3.0 interfaces. Educational literature within the region notes that the curriculum expects students to transition from passive media consumers into active contributors who can independently design digital artifacts, websites, and collaborative platforms. Consequently, standard educational literature underscores a critical instructional mandate: to successfully bridge content gaps in highly technical tracks, pedagogical tools must be deliberately designed to match the rapid, interactive, and media-rich realities of the modern digital landscape.

II. Localized Evaluation of Digital Interventions

The historical trajectory of technology-driven academic performance in the Philippines reveals a long-standing baseline of instructional efficacy. Early research by Dela Cerna (2000) established a baseline for technology-driven instruction, demonstrating significant posttest score gains compared to pretest results through early digital media delivery. This early integration demonstrates how multimedia architectures—the historical foundation upon which modern CAI was conceptualized—serve as an effective baseline for upgrading instructional quality. It anchors abstract, highly technical operational steps into manageable, visually concrete formats that prime students for immediate conceptual mastery.

Building upon this foundation, Gonzales (2002) directly measured the structural efficacy of digital delivery utilizing a rigorous pretest–posttest analytical design to appraise two distinct software models. While both groups demonstrated comparable baseline competencies prior to instruction, the experimental group receiving computer-aided instruction achieved statistically significant posttest gains compared to the control group taught via traditional methods. This evidence aligns precisely with Cognitive Load Theory, illustrating that when CAI software is purposefully structured to assist the learner, it successfully breaks baseline learner parity and accelerates final academic achievement.

In more recent literature, Benabaye (2009) argued that sustaining high academic performance requires addressing the psychological barriers associated with student disengagement through interactive system design. Benabaye (2009) evaluated 'A Web-Based Interactive Multimedia Intelligent Tutoring System (IMITS) for Certain Topics in Information Technology Fundamentals.' The study revealed that traditional, passive instructional methods frequently caused student boredom and cognitive disengagement, which directly threatened academic retention. To bridge this pedagogical gap, Benabaye recommended the systemic implementation of adaptive tutoring architectures, demonstrating that interactive, computerized platforms directly enhance a user's perceived usefulness and ease of use. Consequently, this user acceptance transforms the interface into an optimal learning environment that protects vital cognitive resources for deeper technical comprehension.

Similarly, Tampos (2012) provided empirical support for the affective and motivational prerequisites needed for maximizing academic achievement within localized active learning frameworks. In the study Games as Motivation in Teaching Mathematics, conducted at Tisa Elementary School, Tampos deployed a quasi-experimental design across distinct class sections. Evaluated through a validated teacher-made instrument, the study yielded a statistically significant percentage increase in student academic performance. The study demonstrated that incorporating interactive, goal-oriented instructional mechanics significantly enhances student self-esteem and intrinsic motivation. This confirms that when instructional tools are grounded in active discovery, they foster an optimal affective environment that primes students for deeper cognitive processing and higher test scores.

III. Synthesis of Related Literature

The contemporary convergence of these distinct frameworks is perfectly operationalized by Batarilan (2021) in the study "Computer-Assisted Instruction (CAI) for Grade 9 Mathematics" conducted at Talamban National High School, Cebu City. This quasi-experimental study evaluated separate student sections using a validated 40-item, teacher-made multiple-choice test to gather precise pretest and posttest performance data. Using independent and dependent-samples t-tests, the study found significant differences in the mean gain scores of the experimental group exposed to CAI. Batarilan observed that CAI's capacity to deploy interactive animations, step-by-step demonstrations, and immediate feedback loops enables students to navigate technical workflows at their own pace comfortably. Using independent and paired-samples t-tests, the study confirmed statistically significant differences in the mean score gains of the experimental group exposed to CAI. Ultimately, this localized evidence confirms that a well-structured CAI environment successfully minimizes extraneous cognitive load while maximizing user acceptance, resulting in measurable improvements in students' academic achievement.

Guided by the anchor theory, supporting theories, related literature, and prior studies, this study was conducted to empirically evaluate the effect of custom-designed Computer-Aided Instruction (CAI) on the academic achievement of Grade 12 STEM students in Empowerment Technologies at Pardo National High School during the 2025–2026 school year. The gathered information and findings served as the basis of the proposed action plan.

3. Methodology

Data Collection Procedure

The data collection phase was executed systematically upon receiving institutional clearance. Initially, the researcher submitted a formal request letter to the Principal of Pardo National High School to secure authorization for the study's implementation. Upon approval, the researcher coordinated with the handling teachers and oriented the selected Grade 12 Science, Technology, Engineering, and Mathematics (STEM) sections regarding the scope, objectives, and procedural flow of the study, while ensuring complete compliance with ethical research guidelines.

To establish baseline equivalence before the intervention, the researcher consolidated the subjects' midterm grades in Empowerment Technologies. The participants were balanced and assigned into homogeneous control and experimental groups based on demographic variables (age and gender) and baseline academic standing (midterm grades). Concurrently, the research instrument was submitted to the Technical-Vocational-Livelihood (TVL) Department Head for content validation and expert evaluation. Following expert endorsement, the questionnaire was pilot-tested among a select cohort of non-participating Grade 12 students to establish internal consistency and reliability.

Following group assignment and instrument validation, the operational phase of the study was conducted through a structured, three-stage sequence:

1. **Pretest Administration:** The researcher convened both the control and experimental cohorts in the designated STEM Aries classroom. The validated 40-item instrument was administered as a pretest to all subjects to establish their baseline, pre-intervention cognitive entry levels in Empowerment Technologies.
2. **Instructional Intervention:** Both cohorts were instructed on identical curricular content in Empowerment Technologies. The control group was exposed exclusively to conventional, teacher-led lecture delivery methods, including traditional oral discussions and whiteboard illustrations. Conversely, the experimental group received treatment via custom-designed Computer-Aided Instruction (CAI), which integrated interactive multimedia presentations and self-paced, hands-on computer application workflows. These activities allowed the experimental subjects to manipulate digital variables and apply technical concepts directly through the software interface.

3. **Posttest Administration:** Upon conclusion of the designated instructional periods, the identical validated instrument was re-administered as a posttest to both the control and experimental groups. These data quantified and compared students' final academic achievement and mean gain scores across the two pedagogical environments.

Statistical Treatment of Data

The raw quantitative data gathered from the pretest and posttest instruments were tabulated, coded, and analyzed using standard statistical software. The following statistical tools were deployed to interpret the research data:

- **Frequency Count and Percentage:** Used to organize, categorize, and descriptively summarize the distribution of student performance levels in both the pretest and posttest across the control and experimental cohorts.
- **Independent Samples t-test:** Utilized at two separate junctures. First, it was used to analyze the pretest scores and determine whether the control and experimental groups had comparable baseline performance. Second, it was used post-intervention to determine whether a statistically significant difference existed between the final posttest performances of the two groups.
- **Paired-Samples (Dependent) t-test:** Applied to evaluate the internal academic growth within each group. This test analyzed the difference between the pretest and posttest mean scores within each group, thereby measuring the instructional impact of each methodology.

4. Results/Findings

Pretest Performance and Baseline Parity

The first objective of this study was to evaluate the pretest performances of the control and experimental cohorts to determine their initial cognitive entry levels in Empowerment Technologies. The descriptive statistical analysis revealed that both groups possessed a baseline knowledge level classified as "Good." To answer the third research question regarding whether a significant baseline difference existed between the groups before the intervention, an independent samples t-test was conducted.

The statistical analysis yielded no significant difference between the pretest scores of the control group and the experimental group. This statistical parity indicates successful homogeneous group assignment based on gender, age, and previous midterm grades. Establishing this baseline equivalence is methodologically crucial for a quasi-experimental non-equivalent control group design, as it ensures that any subsequent variance observed in post-intervention metrics can be confidently attributed to the pedagogical treatments rather than pre-existing differences in student aptitude.

Post-Intervention Performance and Group Growth

The second, fourth, and fifth objectives focused on assessing posttest performances, measuring intra-group academic growth, and comparing final inter-group outcomes. Following the instructional period, both cohorts demonstrated substantial academic advancement, with mean scores elevating their descriptive performance classification to "Very Good."

To assess internal academic growth (Questions 4.1 and 4.2), a paired-samples t-test was executed for each group. The results indicated a highly significant difference between the pretest and posttest performances within both the control group and the experimental group. This underscores that both traditional, teacher-led lecture delivery with heavy scaffolding and the technology-mediated Computer-Aided Instruction (CAI) are highly effective instructional modalities capable of driving significant cognitive gains.

To address the fifth research question, an independent-samples t-test was used to compare the final posttest achievement scores of the two groups. The analysis revealed no statistically significant difference between the final posttest performances of the control and experimental groups. While the raw academic achievement metrics aligned, an analysis of internal descriptive data revealed distinct structural variances. The CAI environment produced a tighter standard deviation ($SD = 3.34$), reflecting a higher concentration of top-tier student scores and a more uniform distribution of mastery compared to the traditional cohort.

Theoretical Integration of Findings

The empirical results offer unique insights when viewed through the lenses of Cognitive Load Theory (Sweller, 1988) and the Technology Acceptance Model (Davis, 1989). The significant growth within the experimental group confirms that the custom-designed CAI modules successfully managed the high intrinsic load associated with complex Empowerment Technologies workflows (e.g., advanced digital image manipulation and web design platform navigation). By utilizing interactive animations, step-by-step demonstrations, and immediate feedback loops, the software eliminated the redundancy effect. Tt minimized extraneous cognitive load, allowing working memory resources to be fully directed toward schema automation.

Simultaneously, the high level of post-intervention mastery validates the core tenets of TAM. The intuitive, user-friendly interface of the CAI modules enhanced the students' Perceived Ease of Use (PEOU). According to Davis (1989), elevated PEOU directly enhances Perceived Usefulness (PU), driving behavioral intentions toward active digital exploration. Although traditional teaching yielded comparable final mean scores due to direct teacher interventions and intensive classroom scaffolding, the CAI platform achieved its "Very Good" mastery baseline by shifting the instructional burden onto an automated, self-paced interface. This indicates that while both instruction methods enhance learning outcomes, CAI offers a more structurally efficient, student-centered environment that reduces cognitive load for both teachers and students.

5. Conclusion

Based on the empirical findings, it is concluded that Computer-Aided Instruction (CAI) is a highly effective pedagogical framework for enhancing the academic achievement of Senior High School STEM students in technical subjects like Empowerment Technologies. While both conventional instruction and CAI yield substantial, statistically significant learning gains, CAI introduces distinct operational advantages. The integration of self-paced, technology-driven modules results in a narrower performance variance and a more consistent baseline of student mastery. Ultimately, CAI operationalizes constructivist and cognitive load principles, serving as a viable, resource-efficient equalizer that can standardize instructional quality in public secondary school settings.

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