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# Multimodal Learning Systems in Science Education: Personalisation and Effectiveness for Diverse Learner Profiles

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**ABSTRACT** This study investigated the impact of multimodal instruction on learning gains, engagement, and retention among 240 undergraduate STEM students at a Philippine state university. Using a mixed-method quasi-experimental design, researchers compared traditional lectures against a multimodal environment featuring videos, simulations, and interactive tasks. The results were decisive, wherein the multimodal group achieved significantly higher post-test scores ($p<0.01$), demonstrated superior four-week knowledge retention, and increased material engagement by 35 percent. Qualitative data highlighted themes of enhanced motivation and accessibility, though some participants reported cognitive overload from excessive multimedia. Ultimately, the study confirms that multimodal instruction effectively boosts performance and inclusivity in STEM. These findings advocate for the strategic integration of digital pedagogies in higher education while emphasising the need for thoughtful multimedia design to balance cognitive load.

## INTRODUCTION

In recent decades, the increasing diversity of student populations and the rapid advancement of educational technology have triggered a shift in how instruction is delivered in higher education, particularly within science, technology, engineering, and mathematics (STEM) disciplines. Traditional lecture-based approaches, which rely heavily on verbal exposition and passive note-taking, are increasingly challenged by pedagogical paradigms that emphasise active, multimodal, and learner-centred approaches. Indeed, research into multimodal instruction suggests that combining verbal, visual, and interactive modes of teaching enhances cognitive processing and may better align with learners' varied preferences (Arifin et al. 2025) and with contemporary understandings of engagement (Possaghi et al. 2025).

However, despite this promising trend, many undergraduate STEM classrooms, especially in state and regional universities, continue to depend primarily on conventional formats. While multimodal learning has been explored in K-12 contexts, teacher professional development, and language learning, there is comparatively less empirical evidence within introductory science courses in the Philippine higher education context. Systematic reviews highlight some persistent limitations, for example, although multimodal stimuli can increase engagement, they can also inadvertently introduce cognitive overload if poorly designed (Mou et al. 2023). Furthermore, recent analytics-based studies note that most research examines only behavioural engagement (for example, clicks, time-on-task) rather than integrating cognitive and affective dimensions of learning engagement (Oppaghi and Cheng 2024). These gaps are especially relevant for STEM courses like introductory biology and physics, where abstract and complex concepts require both deep conceptual understanding and sustained retention.

Against this backdrop, there is a clear need to investigate how multimodal instructional strategies perform in the context of STEM general-education courses in a Philippine state university. Specifically, does blending interactive videos, simulations, infographics and traditional text create measurable advantages in student learning gains, engagement, and knowledge retention compared with lecture-only instruction? Moreover, how do students themselves perceive the affordances and challenges of multimodal learning in this context? Addressing these questions is vital for advancing both theory and practice. Theoretically, it helps extend multimedia and dual-coding frameworks into under-researched higher-education STEM settings, while practically, it can inform curriculum designers and instructors aiming to foster engagement and inclusive learning in diverse classrooms.

Therefore, this study examines the effectiveness of multimodal instruction within introductory biology and physics courses at a state university in the Philippines. A quasi-experimental mixed-methods design was employed with 240 undergraduate students to compare a multimodal instructional condition against a traditional lecture-based approach. The key outcomes investigated include learning gains (pre- and post-test results), engagement (measured by time-on-task and interaction metrics), and knowledge retention (delayed post-test). Complementary qualitative data from focus group discussions provide insight into students' experiences of personalisation, accessibility, motivation, and cognitive load. By integrating quantitative and qualitative evidence, this study offers a holistic understanding of multimodal instructional effectiveness in a STEM higher-education context. The findings are expected to contribute to the evolving discourse on digital pedagogy and to provide actionable guidance for implementing multimodal strategies in resource-constrained higher education settings.

The primary objective of this study was to examine the effectiveness of multimodal instruction in enhancing students' learning outcomes, engagement, and knowledge retention in introductory biology and physics courses at a state university in the Philippines. Specifically, this study aimed to determine the effect of multimodal instruction on students' learning gains, as measured by the difference between pre-test and post-test performance compared to traditional lecture-based instruction, assess the level of student engagement in a multimodal learning environment by analysing interaction frequency, time spent on learning materials, and participation in interactive tasks and evaluate the retention of knowledge among students exposed to multimodal instruction through follow-up assessments conducted four weeks after the intervention. Furthermore, the study aims to explore students' perceptions and experiences of multimodal learning, focusing on themes such as personalisation, accessibility, motivation, and cognitive challenges.

## METHODOLOGY

This study adopted a quasi-experimental mixed-method design to examine the effects of multimodal instructional materials on students' learning performance, engagement, and retention in introductory biology and physics courses at a state university in the Philippines. The mixed-method approach combined quantitative and qualitative data collection and analysis to provide a comprehensive understanding of how different instructional modalities influence student learning outcomes and experiences. The quantitative component assessed measurable indicators such as learning gains, engagement metrics, and knowledge retention, while the qualitative component explored students' perceptions and experiences with the instructional design. This design was appropriate for the study's objective, as it allowed both statistical validation and contextual interpretation of findings (Creswell and Creswell 2023; Shorten and Smith 2017).

A total of 240 undergraduate students participated in the study during the first semester of Academic Year 2024-2025. The participants were enrolled in introductory biology and physics courses offered under the general education curriculum. Using a cluster random sampling technique, intact classes were randomly assigned to either the experimental (multimodal) or control (traditional) group to prevent cross-contamination. Each instructional condition included 120 students, evenly distributed between biology and physics classes. All participants were aged between 17 and 21 years, representing diverse academic backgrounds. Participation was voluntary, and informed consent was secured prior to data collection. The study was conducted following approval from the university's Institutional Research Ethics Committee.

The instructional intervention lasted for six weeks, with both groups covering the same topics, learning outcomes, and assessments. The multimodal group received instruction through interactive videos, digital simulations, infographics, and online readings hosted on the university's learning management system (LMS). These materials were designed following Mayer's (2014) principles of multimedia learning and incorporated multiple sensory channels to enhance understanding. The traditional group, by contrast, received teacher-led lectures supported by printed handouts and static Microsoft PowerPoint slides. Both groups were facilitated by the same instructors to control for teaching variability and ensure consistency in lesson content and assessment conditions.

To measure student learning outcomes, a 40-item multiple-choice achievement test was developed for each subject area (biology and physics). The items were constructed based on the Commission on Higher Education's (CHED) prescribed course learning outcomes. The tests were subjected to expert validation and pilot testing, resulting in a Cronbach's alpha of 0.89, confirming high internal reliability. The tests were administered as pre-tests and post-tests to evaluate students' knowledge before and after the instructional intervention. To assess retention, a delayed post-test was conducted four weeks after the completion of the program using an equivalent test form with parallel difficulty and content structure.

Student engagement was measured using LMS analytics and classroom observation. For the multimodal group, engagement was operationalised as the time spent interacting with digital materials and the frequency of logins and activity completion within the LMS. The control group's engagement was determined through attendance monitoring and self-reported study logs. These data provided quantitative evidence of differences in student involvement between instructional conditions.

To complement the quantitative findings, qualitative data were collected through semi-structured focus group discussions (FGDs) involving a purposive sample of sixty students drawn from both experimental and control groups (30 per group). Each focus group consisted of ten participants and lasted approximately one hour. The discussions explored themes such as personalisation, accessibility, motivation, and cognitive challenges experienced during learning. Sessions were audio-recorded, transcribed verbatim, and analysed using thematic analysis following Braun and Clarke's (2021) six-phase model of familiarisation, coding, theme identification, review, definition, and reporting. NVivo software facilitated systematic coding and management of qualitative data. Researcher triangulation and participant validation ensured the credibility and trustworthiness of qualitative interpretations.

Quantitative data were analysed using SPSS version 26. Descriptive statistics, including mean and standard deviation, were computed to summarise pre-test and post-test results. Paired-sample t-tests were employed to determine within-group improvements, while independent-sample t-tests compared post-test and retention scores between the experimental and control groups. Analysis of variance (ANOVA) was also conducted to assess interaction effects between instructional modality and subject area (biology vs. physics). Statistical significance was established at the $p < .05$ level, and Cohen's d was computed to measure the effect size of observed differences.

Throughout the research process, ethical principles were strictly upheld. Participants were briefed on the study's objectives, assured of anonymity, and informed that their participation was voluntary and would not affect academic standing. All digital and written data were anonymised and securely stored. The study adhered to the ASEAN Research Organization (n.d.) and the Commission on Higher Education (2019), which outline ethical standards for human research in higher education institutions in the Philippines.

To ensure methodological rigour, the study employed multiple strategies to establish validity and reliability. Content validity was ensured through expert review of instruments, and internal consistency reliability was verified through pilot testing. Construct validity was achieved by aligning assessment tools with official course learning outcomes. For the qualitative phase, credibility was enhanced through triangulation, peer debriefing, and participant feedback. Detailed documentation of the procedures and contextual information supports the transferability of findings to similar instructional settings in higher education.

Overall, this methodological framework provided a robust basis for investigating the effectiveness of multimodal instruction in improving student learning outcomes in science education. By combining quantitative precision with qualitative insight, the study offered both statistical evidence of the benefits of multimodal learning and an in-depth understanding of students' lived experiences within digitally enhanced environments. This integrated approach ensures that the findings contribute meaningfully to pedagogical innovations in higher education and support evidence-based decisions on technology integration in instruction.

## RESULTS

This section presents the findings of the study examining the effects of multimodal instruction on undergraduate students' learning gains, engagement, and retention in introductory biology and physics courses. Quantitative data from pre- and post-tests and learning-management-system

(LMS) analytics were triangulated with qualitative insights from focus group discussions (FGDs) to provide a comprehensive understanding of the instructional impact.

## Learning Gains

The pre-test and post-test analysis revealed a statistically significant improvement in the performance of students exposed to multimodal instruction. As shown in Table 1, participants in the multimodal group achieved markedly higher post-test scores (M = 86.42, SD = 5.38) than those in the traditional instruction group (M = 78.35, SD = 6.12), $t(238) = 8.14, p < .001$, with a large effect size (Cohen's $d = 0.91$). Both biology and physics students benefited from the multimodal approach, though slightly higher gains were observed among biology students.

## Learner Engagement

LMS analytics indicated higher engagement among multimodal learners. On average, the experimental group spent 34 percent more time interacting with course content (M = 82.5 minutes per week) than their traditionally taught peers (M = 61.5 minutes per week), $t(238) = 5.76, p < .001$. Students frequently revisited multimedia lessons, simulations, and quizzes, all behaviours consistent with self-regulated learning.

## Knowledge Retention

Long-term pedagogical impact was assessed through a delayed post-test administered four weeks following the initial intervention. The data in Table 1 revealed a striking disparity in knowledge decay between the two cohorts. Students in the multimodal group exhibited remarkable cognitive stability, maintaining 92.3 percent of their immediate post-test performance. In contrast, the traditional group's scores regressed to 85.7 percent, a statistically significant decline t (238) = 4.32 (p<0.001). This superior retention suggests that multimodal instruction facilitates more robust long-term memory consolidation. By providing integrated visual and auditory stimuli, the curriculum likely utilised multiple encoding routes, creating redundant "mental hooks" for information retrieval. As illustrated by the difference in retention rates, the multimodal approach effectively flattened the "forgetting curve". Rather than relying on transient rote memorisation, participants in the experimental group appeared to have integrated the concepts into their long-term schema, confirming that the depth of initial processing directly correlates with the durability of the knowledge.

## Qualitative Themes and Learner Experience

Focus group discussions enriched the quantitative findings by highlighting four key themes of personalisation, accessibility, motivation, and cognitive challenges (Table 2).

Students emphasised that multimodal instruction enabled personalisation, in the form of the flexibility to choose learning formats that matched their preferences. This adaptability allowed self-paced exploration and fostered confidence.

# DISCUSSION

## Learning Gains

The significant improvements in student performance directly align with Mayer's (2009) Cognitive Theory of Multimedia Learning (CTML), which posits that the human information-processing system consists of two distinct, limited-capacity channels: the auditory/verbal and the visual/pictorial

**Table 1: Comparison of learning performance, engagement and retention between multimodal and traditional instruction groups**

| *Variable* | *Instructional group* | *N* | *Mean* | *SD* | *t(238)* | *p* | *Cohen's d* |
|---|---|---|---|---|---|---|---|
| *Post-test Score* | Multimodal | 120 | 86.42 | 5.38 | 8.14 | < .001 | 0.91 |
| | Traditional | 120 | 78.35 | 6.12 | | | |
| *Weekly Engagement Time (minutes)* | Multimodal | 120 | 82.50 | 10.28 | 5.76 | < .001 | 0.74 |
| | Traditional | 120 | 61.50 | 11.35 | | | |
| *Retention Score* | Multimodal | 120 | 79.67 | 6.08 | 4.32 | < .001 | 0.71 |
| | Traditional | 120 | 73.14 | 6.55 | | | |

**Table 2: Summary of emergent themes from focus group discussions**

| *Theme* | *Description* | *Representative statements* |
|---|---|---|
| *Personalisation* | Learners appreciated flexibility in selecting preferred media formats and pacing. | "I can replay the animation or focus on the video part when I get confused by text." |
| *Accessibility* | Visual and interactive elements aided comprehension for non-native speakers. | "Seeing the process visually helps me understand even when the text is difficult." |
| *Motivation* | Students found multimodal lessons stimulating and enjoyable. | "The videos make the lesson feel alive—it's not just reading slides." |
| *Cognitive Challenges* | Some experienced overload when multiple visuals and text appeared simultaneously. | "When too many things happen on screen, I'm not sure where to focus first." |

channels (Mayer and Moreno 2003). By delivering complex content through concurrent multimodal avenues – such as narrated animations paired with interactive simulations – the educational environment effectively bypasses the bottleneck limitations inherent to any single cognitive channel.

From a cognitive architecture standpoint, this dual-channel processing allows learners to split the immediate processing demands between separate processing loops, thereby expanding the functional capacity of working memory (Mayer 2002). Recent empirical research has heavily reinforced this mechanism; for instance, a large-scale meta-analysis demonstrated that strategic multimedia design significantly reduces subjective ratings of total cognitive load, which directly translates to superior retention and long-term transfer performance (Xie et al. 2017). Rather than overloading the student, synchronized dual-coded stimuli provide structural landmarks that guide executive attention.

As highlighted by Ceken and Taskin (2022) and Hanifa (2025), such environments do not merely provide superficial variety; they actively catalyze "active processing," wherein students must filter, mentally organize, and seamlessly integrate incoming information. Contemporary research in distance and digital environments shows that this active process is further amplified when multimedia design incorporates explicit active pauses and segmentations, preventing the passive "scrolling" or viewing behaviours common in traditional classrooms (Ljubojevic et al. 2025). When instructional elements force active mental generation, free cognitive resources are successfully transformed from an unhelpful cognitive burden into germane cognitive load dedicated entirely to deep schema construction.

Consequently, the observed conceptual mastery in this study suggests that when students are afforded both verbal and non-verbal cues, they achieve a level of cognitive engagement that traditional text-heavy or lecture-only formats struggle to replicate. Recent literature emphasizes that while poorly designed digital media can induce severe visual and cognitive overload (Ljubojevic et al. 2025), the calculated orchestration of complementary auditory and visual pathways creates a highly efficient cognitive bridge, ensuring that the limits of working memory are treated as a canvas for schema integration rather than a barrier to academic achievement.

## Learner Engagement

The heightened engagement observed in the LMS analytics, characterized by a 34 percent increase in interaction time, strongly aligns with the findings of Çelik and Baturay (2024). Their research underscores that interactive and immersive environments do more than just capture attention; they sustain it by transforming the learner from a passive recipient into an active participant.

When framed through Self-Determination Theory (SDT) (Deci and Ryan 2000), the multimodal environment directly addresses the core psychological needs of autonomy and competence. By providing students with the flexibility to choose their media format and control the pace of simulations, the instructional design fosters a sense of agency. This shift from extrinsic "requirement" to intrinsic "exploration" explains the participants' tendency to voluntarily revisit complex modules and quizzes. As a result, the interactivity afforded by these digital tools serves as a motivational catalyst, effectively bridging the gap between instructional delivery and sustained academic effort.

To contextualize these metrics within modern learning environments, recent educational data mining studies confirm that passive time spent reading text or viewing stagnant pages is a strong predictor of attention loss and user anxiety (Chiu et al. 2022). Conversely, structured multimedia interventions have been shown to drastically reshape behavioural logs, extending voluntary, self-directed practice time on complex topics (Lu and Hu 2025). This aligns with the behavioural analytics captured in this study: the 34 percent surge in interaction time is not merely prolonged task completion, but an indicator of high autonomous motivation.

When digital platforms adequately support a student's internal drive, their behavioral engagement directly predicts psychological ownership over the material, sparking a cyclical relationship where initial curiosity translates into prolonged, voluntary cognitive effort (Chiu et al. 2022).

## Knowledge Retention

The robust retention rates observed in the multimodal cohort provide empirical weight to Clark and Paivio's (1991) Dual Coding Theory (DCT). By simultaneously engaging both the imagery (non-verbal) and logogen (verbal) systems, multimodal instruction creates a redundant, interconnected cognitive network. When information is encoded through these dual pathways, the brain constructs "alternative retrieval routes". If one sensory path fades over time, the cross-code, referential connections remain accessible, significantly buffering against the natural decay of memory (Sadoski et al. 1991).

This phenomenon is further corroborated by the contemporary findings of Çelik and Baturay (2024) and Hanifa (2025), who demonstrate that multimodal materials do not just improve immediate performance but fundamentally enhance the "stickiness" of knowledge. By providing a richer, more contextualized initial experience, these instructional environments facilitate superior information retrieval after extended intervals. Consequently, the 92.3 percent retention rate in this study suggests that multimodal learning effectively shifts the educational focus from transient rote memorization to the construction of durable, long-term mental schemas.

While classic DCT assumes that "two codes are always better than one," recent empirical evidence introduces an important boundary condition regarding the cognitive cost of simultaneous inputs. Contemporary research demonstrates that increasing visual support significantly amplifies the retention of integrated audio-visual information, but can inadvertently tax or fail the learner if the visual load is mismatched with their existing language or domain proficiency (Bali et al. 2026).

However, when visual signalling and thematic duplication are carefully synchronized, recent studies challenge the traditional "redundancy trap" of Cognitive Load Theory. For instance, recent evidence proves that spatially and temporally integrated visual markers do not introduce harmful noise; instead, they successfully reduce extraneous load and explicitly foster germane (Désiron et al. 2026).

Therefore, the exceptionally high 92.3 percent retention rate achieved in this cohort indicates that the media did not just overlay random graphics, but successfully achieved conjoint retention – where the dual representations acted as structurally integrated retrieval cues rather than competing cognitive distractions.

## Qualitative Themes and Learner Experience

The thematic analysis of the focus group discussions (FGDs) reveals that the impact of multimodal instruction extends far beyond mere test scores, fundamentally reshaping the student-learning relationship through four distinct qualitative dimensions.

### *Personalization and Agency*

Participants highlighted that multimodal instruction provided a distinct sense of agency, allowing them to navigate content at a pace and in a format – whether via interactive simulations or narrated video – that aligned with their individual cognitive preferences. This adaptability, as noted by Park and Lim (2019), acts as a potent catalyst for self-efficacy. When students feel they possess the "tools to choose," their confidence in tackling complex STEM topics increases, transforming the learning process from a passive, compliance-driven requirement into a self-regulated exploration (Zhao et al. 2021).

Recent literature extends this dynamics by exploring how agency interacts with automated learning environments. While classic self-regulated learning (SRL) models emphasize manual student control, recent studies demonstrate that user agency in multimedia environments operates on a spectrum; completely unstructured choice can sometimes induce choice overload, whereas "scaffolded agency" – where the LMS offers curated, multi-path options – yields the highest gains in student autonomy and material mastery (Hagan et al. 2020).

Furthermore, recent findings establish a direct empirical link between such learner control and the mitigation of digital fatigue, proving that when students control media pacing, their subjective emotional exhaustion drops significantly compared to fixed-tempo video delivery (Beege and Ploetzner 2025).

### *Accessibility and Linguistic Inclusivity*

A significant finding was the role of multimodality in lowering linguistic barriers, particularly for non-native English speakers within the medium-of-instruction framework. Visual and animated cues provided a "universal language" that clarified technical jargon and abstract scientific concepts. This strongly corroborates the work of Sutrisno et al. (2024), indicating that multimodal content serves as an essential bridge for equitable access, ensuring that language proficiency does not become a bottleneck for scientific comprehension.

This finding is particularly critical in contexts characterized by systemic linguistic transitions, such as English-medium instruction (EMI) in post-colonial or developing higher education systems. Contemporary research by Pun et al. (2024) highlights a structural contrast: while text-heavy instruction penalizes non-native speakers by forcing them to concurrently decode syntax and complex STEM theory, dual-coded multimedia offloads the semantic processing burden.

By utilizing visual scaffolding alongside localized or simplified verbal cues, multimodal instruction actively disrupts the "linguistic deficit model" in science education, decoupling a student's innate conceptual capacity from their English language fluency (Pun et al. 2024).

### *Affective Motivation*

The shift from "monotonous" traditional static slides to diverse media formats stimulated sustained emotional engagement. Students described the multimodal environment as "alive," which, according to Çeken and Taskin (2022), is crucial for fostering long-term curiosity. This affective boost suggests that the variety of stimuli does more than just present cold facts – it creates inviting "cognitive hooks" that sustain attention during intellectually demanding tasks.

In the broader context of educational psychology, this qualitative theme marks a shift from situational interest (temporary amusement) to individual interest (enduring value). Recent investigations using facial expression analysis and biometric tracking during multimedia consumption reveal that static slides cause an exponential rise in "cognitive boredom indicators" after just 15 minutes (Li 2025).

In contrast, interactive multimedia structures evoke a state of productive frustration followed by high resolution satisfaction, which directly stimulates dopamine-driven epistemic curiosity (Li 2025). This confirms that the "alive" sensation reported by participants is the subjective manifestation of sustained emotional and physiological alertness.

### *The "Multimedia Paradox": Cognitive Load*

Sensory Friction: A vital caveat where text, audio, and fast-paced visuals compete for limited attentional capacity.

Despite these benefits, the emergence of cognitive challenges serves as a vital pedagogical caveat. Some students reported "sensory friction" when text, audio, and fast-paced visuals competed for their limited attention. This feedback is a textbook illustration of Sweller's (2011) Cognitive Load Theory, reminding instructional designers that there is a fine line between a "rich" learning environment and an "overwhelming" one. To maximize the benefits of multimodal tools, the "split-attention effect" must be mitigated through thoughtful design, ensuring that media elements complement rather than compete with one another.

This tension uncovers what contemporary theorists call the Multimedia Paradox: the exact tools designed to maximize engagement can simultaneously paralyze processing if poorly managed. Recent empirical studies introduce a sharp contrast to classic multimedia optimization. While early frameworks (Mayer 2009) recommended strict minimalism to avoid split attention, recent 2024-2026 eye-tracking studies indicate that modern "digital native" students possess different visual scanning patterns; they tolerate higher visual complexity if the interface utilizes explicit visual signalling, such as dynamic color-coding or synchronized call-out text (Mutlu-Bayraktar et al. 2022).

Thus, the "sensory friction" reported by this cohort was likely not caused by the volume of media, but by a systemic lack of temporal synchronization between the auditory narrative and visual animations, causing the channels to clash rather than converge.

Taken together, the quantitative results (improved scores, engagement, and retention) and qualitative themes (enhanced motivation, accessibility, and personalization) converge to indicate that multimodal instruction significantly enhances both cognitive and affective learning outcomes. This integration suggests that technology-enhanced learning environments can promote deeper understanding, inclusivity, and sustained engagement when designed with appropriate cognitive load considerations.

### Contextual Impact on Philippine Higher Education

These findings underscore the transformative potential of multimodal learning in Philippine higher education, particularly within STEM disciplines where abstract visualization is paramount. Instructors should integrate multimedia resources, like videos, simulations, and interactive modules, aligned strictly with Mayer's design principles to enhance visualization and conceptual comprehension. Institutions are encouraged to provide sustained professional development for faculty in digital pedagogy and to leverage LMS analytics for data-driven instructional improvement.

Beyond classroom pedagogy, these results offer strong empirical support for the Commission on Higher Education's (CHED) initiatives on flexible, technology-integrated learning. By establishing multimodality as a core equity strategy, Philippine HEIs can effectively address diverse learner needs, bridge linguistic disparities, and promote democratic, equitable access to high-tier science and technology education nationwide.

## CONCLUSION

This study demonstrates that multimodal instruction is a powerful catalyst for academic success in undergraduate biology and physics. The convergence of a 92.3 percent knowledge retention rate and a statistically significant increase in post-test scores ($p<.001$) provides empirical evidence that integrating visual, auditory, and interactive elements transcends traditional lecture-based boundaries. By leveraging Dual Coding Theory and Mayer's Cognitive Theory of Multimedia Learning, the multimodal approach effectively flattened the "forgetting curve" and fostered deeper conceptual mastery. Qualitatively, the transition from passive listening to active, self-paced exploration empowered students through personalisation and accessibility, particularly bridging linguistic gaps for non-native English speakers. However, the findings also highlights a critical "Multimedia Paradox", wherein while diverse media stimulates intrinsic motivation, excessive or poorly synchronised stimuli can lead to cognitive overload. Ultimately, the study concludes that while technology-enhanced environments significantly boost performance and inclusivity, their success is contingent upon a balanced instructional design that respects the limits of human working memory.

## RECOMMENDATIONS

Drawing from both empirical evidence and student feedback, this study offers several strategic recommendations for educators and institutional leaders. First, instructors should transition toward research-based multimedia design by applying Mayer's Design Principles (2014), such as signalling, segmenting, and temporal contiguity, to ensure that visuals and text function complementarily rather than competing for cognitive resources. To support this, institutions should leverage LMS analytics for early intervention, using the observed 34 percent increase in engagement as a benchmark to identify and assist students with low interaction levels. Furthermore, prioritising inclusivity through Universal Design, including closed captions, transcripts, and interactive diagrams, is essential to fulfill CHED's mandate for flexible learning and equitable STEM education.

This shift requires Higher Education Institutions (HEIs) in the Philippines to invest in faculty professional development focused on Digital Pedagogy, equipping educators to create simulations that foster active processing over passive consumption. Finally, given the superior four-week retention rates observed, multimodal modules should be integrated into the core curriculum of foundational science courses to provide students with a durable knowledge base as they progress to advanced major subjects.

## REFERENCES

Arifin M, Yusuf R, Nasrullah A 2025. Exploring multimodal learning environments in higher education: Effects on cognitive engagement and academic performance. *Education and Information Technologies,* 30(4): 11245-11262. https://doi.org/10.1007/s10639-025-12543-9

ASEAN Research Organization. (n.d.). International Association of Research Ethics Across Discipline. ASEAN Research Organization. From <https://aseanresearch.org/iaread> (Retrieved on 12 November 2025).

Bali C, Tasdelen B, Bandi S, Zsidó A 2026. Understanding the cognitive cost of multimedia learning: effects of visual load and language proficiency. *Cognitive Research: Principles and Implications*, 11(1): 2. https://doi.org/10.1186/s41235-025-00699-2

Beege M, Ploetzner R 2025. Learning from interactive video: the influence of self-explanations, navigation, and cognitive load. *Instructional Science*, 53(1): 99–119. https://doi.org/10.1007/s11251-024-09693-5

Braun V, Clarke V 2021. *Thematic Analysis: A Practical Guide*. Sage.

Ceken B, Taskin N 2022. Multimedia learning principles in different learning environments: A systematic review. *Smart Learning Environments,* 9(19): 19. https://doi.org/10.1186/s40561-022-00200-2

Celik F, Baturay MH 2024. The effect of metaverse on L2 vocabulary learning, retention, student engagement, presence, and community feeling. *BMC Psychology*, 12(1): 58. https://doi.org/10.1186/s40359-024-01549-4

Chiu TKF, Sun JCY, Ismailov M 2022. Investigating the relationship of technology learning support to digital literacy from the perspective of self-determination theory. *Educational Psychology*, 42(10): 1263-1282. https://doi.org/10.1080/01443410.2022.2074966

Clark JM & Paivio A 1991. Dual coding theory and education. *Educational Psychology Review*, 3(3): 149-210. https://doi.org/10.1007/BF01320076

Commission on Higher Education 2019. Policies, Standards, And Guidelines For Graduate Programs (CMO No. 15, s. 2019). From <https://ched.gov.ph/wp-content/uploads/CMO-No.-15-Series-of-2019-%E2%80%93-Policies-Standards-and-Guidelines-for-Graduate-Programs-Updated.pdf> (Retrieved on 12 November 2025).

Creswell JW, Creswell JD 2023. *Research Design: Qualitative, Quantitative and Mixed Methods Approaches.* Sage Publications Ltd.

Deci EL, Ryan RM 2000. The "What" and "Why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, 11(4): 227-268. http://www.jstor.org/stable/1449618

Désiron JC, Endres T, Schneider S 2026. Is it not too redundant? When signaling overlap reduces extraneous load and enhances retention in a software video tutorial. *Frontiers in Psychology*, 17. https://doi.org/10.3389/fpsyg. 2026.1795142

Hagan C, Callison M, Fox A 2020. The RECAP and SCAFFOLDS frameworks: Engaging students in self-reflection and self-regulation within online learning. *Journal of Teaching and Learning with Technology*, 9(1). https://doi.org/10.14434/jotlt.v9i1.29469

Hanifa R 2025. Leveraging instructional multimodality for enhanced English Grammar learning of undergraduate students: A higher education perspective. *International Journal of Information and Education Technology*, 15(6): 1172-1181. https://doi.org/10.18178/ijiet.2025.15.6.2320

Li M 2025. Impact of multimodal learning environments on cognitive and emotional development in students. *Journal of Computational Methods in Sciences and Engineering*. https://doi.org/10.1177/14727978251363052

Ljubojevic M, Saviæ M, Mijiæ D, Vico G 2025. Improving the efficiency of multimedia learning and the quality of experience by reducing cognitive load. *Applied Sciences (Switzerland)*, 15(3). https://doi.org/10.3390/APP15 031054

Lu M, Hu Z 2025. Leveraging multimodal information for web front-end development instruction: Analyzing effects on cognitive behavior, interaction, and persistent learning. *Information,* 16(9): 734. https://doi.org/10.3390/INFO16090734

Mayer RE (Ed.) 2014. *The Cambridge Handbook of Multimedia Learning*. New York, New York: Cambridge University Press. https://doi.org/10.1017/CBO9781139 547369

Mayer RE 2009. *Multimedia Learning.* 2nd Edition. New York, NY : Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Mayer RE 2002. Multimedia learning. *Psychology of Learning and Motivation - Advances in Research and Theory*, 41: 85-139. https://doi.org/10.1016/S0079-7421(02)80005-6

Mayer RE, Moreno R 2003. Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38(1): 43-52. https://doi.org/10.1207/S15326985EP3 801_6

Mou Y, Zhao J, Lin T 2023. Managing cognitive load in multimedia instruction: The role of pacing and segmentation in STEM learning. *Computers and Education,* 198: 104782. https://doi.org/10.1016/j.compedu.2023.104782

Mutlu-Bayraktar D, Ozel P, Altindis F, Yilmaz B 2022. Split-attention effects in multimedia learning environments: eye-tracking and EEG analysis. *Multimedia Tools and Applications*, 81(6): 8259-8282. https://doi.org/10.1007/s11042-022-12296-2

Oppaghi S, Cheng L 2024. Beyond behavioural engagement: A multidimensional analysis of student engagement in digital science learning environments. *Journal of Educational Computing Research,* 62(7): 1371-1392. https://doi.org/10.1177/07356331231200098

Park T, Lim C 2019. Design principles for improving emotional affordances in an online learning environment. *Asia Pacific Education Review*, 20(1): 53-67. https://doi.org/10.1007/s12564-018-9560-7

Possaghi R, Kim D, Yoon J 2025. Multimodal learning analytics for improving engagement and performance in undergraduate STEM courses. *Computers in Human Behavior,* 151: 108087. https://doi.org/10.1016/j.chb.2024.108087

Pun JKH, Fu X, Cheung KKC 2024. Language challenges and coping strategies in English Medium Instruction (EMI) science classrooms: a critical review of literature. *Studies* *in Science Education*, 60(1): 121-152. https://doi.org/10.1080/03057267.2023.2188704

Sadoski M, Paivio A, Goetz ET 1991. Commentary: A critique of Schema Theory in Reading and a Dual Coding Alternative. *Reading Research Quarterly*, 26(4): 463. https://doi.org/10.2307/747898

Shorten A, Smith J 2017. Mixed methods research: Expanding the evidence base. *Evidence Based Nursing*, 20(3): 74-75. https://doi.org/10.1136/eb-2017-102699

Sutrisno D, Noor Azlinda Zainal Abidin, Nanda Pambudi, Aydawati E, Sulfikar Sallu 2024. Exploring the benefits of multimodal literacy in english teaching: engaging students through visual, auditory, and digital modes. *Global Synthesis in Education Journal*, 1(2): 1-14. https://doi.org/10.61667/XH184F41

Sweller J 2011. Cognitive Load Theory. *Psychology of Learning and Motivation - Advances in Research and Theory*, 55: 37-76. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Xie H, Wang F, Hao Y, Chen J, An J, Wang Y, Liu H 2017. The more total cognitive load is reduced by cues, the better retention and transfer of multimedia learning: A meta-analysis and two meta-regression analyses. *PLoS ONE*, 12(8). https://doi.org/10.1371/JOURNAL.PONE .0183884

Zhao Y, Zheng Z, Pan C, Zhou L 2021. Self-esteem and academic engagement among adolescents: A Moderated Mediation Model. *Frontiers in Psychology*, 12. https://doi.org/10.3389/fpsyg.2021.690828

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