

# Game-Based Digital Simulation on Chemical Reaction for Deaf Learners

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## **Abstract:**

This study determined the effectiveness of a Game-Based Learning (GBL) through digital simulations in teaching the conceptual understanding of chemical reactions to Grade 10 deaf learners of Naga Special Education Center, Naga, Cebu, during the Third Quarter of the School Year 2025–2026 as a basis to propose an enhanced game-based instructional model. The research aimed to integrate digital simulations and inclusive teaching strategies tailored to the visual-spatial strengths and communication needs of deaf learners particularly in describing the indicators for a chemical, identifying common acids, bases, and salts using different indicators, and describing important types of chemical reactions. A single-case study design with quantitative emphasis was employed, involving seven deaf learners as embedded units of analysis. The game-based instructional model, grounded in Game-Based Learning Theory, Constructivist Learning Theory, and Gardner’s Multiple Intelligences Theory, the research addressed persistent challenges in teaching abstract chemistry concepts to deaf students, particularly those arising from linguistic barriers in Filipino Sign Language and the visual demands of science instruction. Statistical analysis confirmed a significant difference between pre-test and post-test scores, with very large effect sizes, demonstrating the substantial impact of Game-Based Learning on deaf learners’ learning outcomes and engagement levels. Most learners demonstrated moderate to high conceptual improvement. Engagement and motivation were consistently rated high, reflecting the positive impact of visually rich, interactive simulations. Findings indicated notable increases in post-test scores across competencies, with most learners demonstrating moderate to high conceptual gains. Engagement and motivation were rated at high levels, suggesting that visually rich and interactive simulations effectively supported comprehension and participation. The results highlight the potential of digital game-based simulations to reduce cognitive load, leverage visual-spatial strengths, and address instructional gaps in inclusive science classrooms. The study proposes an Enhanced Game-Based

Instructional Model tailored for deaf learners, contributing to inclusive and technology-mediated science education practices in the Philippine SPED context.

**Keywords:** Game-Based Learning, Digital Simulations, Deaf Learners, Chemical Reactions, Inclusive Education, Visual-Spatial Learning, Science Instruction

## Introduction

### Rationale of the Study

Inclusive education provides meaningful benefits to learners, families, schools, and communities by ensuring that all students regardless of ability, gender, age, or disability is given equitable access to quality education. Central to this principle are appropriate accommodations and modifications in curriculum content, instructional strategies, and assessment approaches, all guided by a shared vision of inclusion. This vision says that every child should have a meaningful role in the learning process. Such commitment is consistent with the Education for All (EFA) framework, which emphasizes welcoming diversity in schools and fostering equality and respect among learners. **Error! Reference source not found..**

Despite strong policy support, the implementation of inclusive education continues to face significant challenges. These include limited instructional resources, insufficient teacher preparation, varying levels of teacher readiness in handling learners with disabilities, and inconsistent acceptance of inclusive practices among stakeholders. These challenges become more pronounced when abstract and conceptually demanding subjects, such as science, are taught to learners with special needs. For deaf learners in self-contained classrooms, the teaching–learning process may be further constrained by communication barriers, particularly when teachers and students struggle with Filipino Sign Language (FSL).

At the Naga Special Education Center, teachers often experience difficulty in delivering the expected competencies each quarter due to delays in instruction, as lessons must be conveyed through Filipino Sign Language (FSL), and many terms in chemistry are complex and challenging to translate and expound accurately. This instructional gap has led to very poor results in the National Achievement Test (NAT) for Grade 10 Science, where students achieved a problem-solving score of only 22.22 and a critical thinking score of 19.44. With an overall Mean Percentage Score (MPS) of only 24.35, the school currently ranks at the bottom of all junior high schools within the division, highlighting an urgent need for a more effective pedagogical framework.

Studies also indicate that many members of the Deaf community in the Philippines, including educators, are more familiar with American Sign Language (ASL) than FSL due to historical influences during the early 20th century. **Error! Reference source not found. Error! Reference source not found..** The mandated use of FSL, combined with English as the prescribed medium of instruction for Science, creates additional cognitive and linguistic challenges for deaf learners. These constraints significantly affect their comprehension of scientific concepts, especially chemical reactions, which require abstract reasoning, symbolic interpretation, and sequential explanation.

To address these challenges, teachers must adopt innovative and inclusive pedagogical approaches that align with the learning strengths of deaf students. Game-Based Learning (GBL) through digital simulations offers a promising instructional strategy by transforming science lessons into visually rich, interactive, and engaging experiences. Digital simulators allow learners to manipulate variables, visualize chemical reactions, and receive immediate feedback within a safe and motivating environment. Subtitles and visual cues embedded in simulations further support comprehension by reducing language barriers.

By leveraging the visual–spatial strengths of deaf learners, GBL promotes active learning, enhances information and communication technology (ICT) skills, and increases motivation and participation. The effectiveness of this approach, however, largely depends on teachers’ readiness, adaptability, and competence in implementing inclusive digital strategies. This study seeks to examine the effectiveness of game-based learning through digital reaction simulators in enhancing deaf learners’ understanding of chemical reactions and to propose an enhanced instructional model for inclusive Science education.

Several studies conducted in the Philippines have examined the effectiveness of game-based learning (GBL) and digital instructional strategies in improving learners’ academic performance, engagement, and motivation across various subject areas.

In chemistry education, **ConelError! Reference source not found.** investigated the use of manipulative game-based learning strategies among Grade 9 learners and found a significant improvement in students’ achievement and conceptual understanding compared to traditional teaching approaches. The study emphasized that game-based activities promote active participation and meaningful learning, particularly in abstract chemistry concepts.

Similarly, **Leaño, BelgicaError! Reference source not found.** explored the use of game-based lesson activities in junior high school chemistry classes. Their findings revealed that learners exposed to game-based instruction demonstrated higher engagement and improved academic performance. The authors recommended the integration of game-based strategies to support differentiated and learner-centered instruction in science.

In mathematics education, **Dela Cruz, JavierError! Reference source not found.** conducted an action research study on the integration of digital and non-digital game-based learning strategies among Grade 7 learners. Results showed significant gains in academic performance, motivation, and classroom participation, indicating that GBL is an effective pedagogical approach in the Philippine basic education context.

A growing body of research has shown that digital game-based learning (DGBL) can enhance student engagement and deepen conceptual understanding in science and STEM education. It indicates that DGBL produces positive effects on learning outcomes when compared to traditional instruction, and case studies in science education contexts suggest gains in engagement and cognitive involvement through interactive game environments.

Research on educational technology in special education also supports the potential of digital tools for learners with disabilities. **Obenza-Tanudtanud, ObenzaError! Reference source not found.** reported that educational digital games positively influenced academic performance and motivation among primary learners, highlighting the value of interactive technologies in inclusive classrooms.

Moreover, **Ramos, Padilla** examined the integration of assistive and instructional technologies for learners with special educational needs in Philippine schools. Their study found that technology-enhanced instruction improved learner engagement and accessibility, but emphasized the need for more targeted studies focusing on specific disability groups.

In the context of deaf education, **Flores, Villanueva** explored the use of technology-mediated instructional strategies to support science learning among deaf learners. The study demonstrated that visually supported digital tools enhanced conceptual understanding and learner participation. However, the research did not specifically examine game-based learning or digital simulations in chemistry instruction.

Although existing Philippine studies provide strong evidence supporting the effectiveness of Game-Based Learning and digital instructional tools in enhancing academic performance and engagement, several gaps remain very evident like limited focus on deaf learners in science education and lack of inclusive instructional models.

This prompted the researcher to conduct a study about the effectiveness of Game-Based Learning through digital simulations in enhancing deaf learners' understanding of chemical reactions, engagement, and motivation in Grade 10 science classroom setting. The study aims to produce an enhanced Game-Based Instructional Model for deaf learners in Science, integrating digital simulations and inclusive teaching strategies tailored to the visual-spatial strengths and communication needs of deaf learners.

### **Theoretical Background of the Study**

The teaching and learning of science, particularly abstract concepts such as chemical reactions, continue to present significant challenges in inclusive classrooms where learners have diverse cognitive, linguistic, and sensory learning needs. Deaf learners, in particular, encounter barriers due to limited access to auditory instruction and reliance on visual communication modalities. Traditional methods of teaching science may not fully address these learners' strengths or preferred ways of processing information, resulting in gaps in comprehension and participation.

Recent developments in learning sciences emphasize that effective instruction should align with how the brain processes, organizes, and retains information, particularly in multimodal and technology-enhanced environments. **Error! Reference source not found.** These viewpoints underscore the importance of reducing unnecessary cognitive load and designing instructional materials that support meaningful learning experiences.

This study is anchored on Constructivist Learning Theory, Cognitive Load Theory, Game-Based Learning (GBL), and the Science of Learning for Deaf Students by Marschark and Knoors. Constructivist Learning Theory emphasizes that learners actively construct knowledge through meaningful interaction with content and experience. Cognitive Load Theory further supports the design of instruction that minimizes extraneous mental effort to facilitate understanding of complex scientific concepts. Game-Based Learning (GBL) has been widely recognized in recent research. **Error! Reference source not found.** as an effective approach to enhance engagement, motivation, and experiential learning through interactive digital environments.

Complementing these is the Science of Learning for Deaf Students. **Error! Reference source not found.**, which conceptualizes deaf and hard-of-hearing learners as a distinct group with unique visual-spatial processing and language development pathways rather than simply hearing learners without hearing. This framework emphasizes that deaf learners primarily process information through visual-spatial channels instead of auditory-sequential modes, requiring instruction that is highly visual, structured, and conceptually concrete. It also explains that difficulties in science learning among deaf students often arise from a mismatch between traditional auditory-based instruction and their cognitive processing characteristics. While deaf learners may develop strengths in visual-spatial reasoning and mental imagery, they may also face challenges in sequential processing tasks essential for understanding step-by-step scientific processes such as chemical reactions.

Together, these theories provide a comprehensive and updated foundation for designing inclusive, visually rich, and cognitively aligned instructional approaches that support deaf learners in understanding abstract scientific concepts.

Furthermore, this framework emphasizes the profound impact of "language deprivation" and the lack of "incidental learning" on academic achievement. Most deaf children arrive at school with significant delays in language development because they lack full access to the spoken language used in their homes and communities. This gap in early language exposure limits their "knowledge of the world" and social-cognitive skills, such as Theory of Mind, which are essential for understanding abstract concepts and the perspectives of others. **Error! Reference source not found.** In a specialized setting like the Naga Special Education Center, these barriers are exacerbated when students must navigate a science curriculum that relies heavily on complex terminology that is

difficult to translate into Filipino Sign Language (FSL). The Science of Learning theory argues that for instruction to be effective, it must bypass these linguistic bottlenecks by leveraging the visual and interactive strengths of the learner.

Instructional strategies such as Game-Based Learning (GBL) and digital simulations align directly with this theory by providing a multimodal learning environment that reduces the cognitive load associated with traditional lectures **Error! Reference source not found.** Digital simulators allow deaf learners to visualize invisible molecular interactions and manipulate variables in real-time, transforming abstract chemistry concepts into concrete, spatial experiences. This approach effectively addresses the "split-attention effect," where deaf students struggle to watch a signer while simultaneously looking at written materials, by integrating visual cues and immediate feedback within a single interactive interface **Error! Reference source not found.** By moving beyond the "deficiency model" of deafness and adopting pedagogy that honors the visual-spatial intelligence of DHH students, educators can create a more equitable pathway to academic success and higher performance in critical subjects like Science.

To overcome these challenges, innovative instructional strategies that leverage technology, interactivity, and learner-centered approaches are necessary. This study is anchored on the integration of Game-Based Learning (GBL) through digital simulation tools, grounded in established educational theories that promote active, experiential, and differentiated learning.

The theoretical framework provides a foundation for understanding how interactive digital tools can enhance engagement, comprehension, and motivation among deaf learners in grade 10 science classrooms. Specifically, the framework draws upon three key theories: Game-Based Learning Theory, which emphasizes the pedagogical value of games and simulations in fostering active and meaningful learning; Constructivist Learning Theory, which underscores learners' active construction of knowledge through experience and interaction; and Multiple Intelligences Theory, which highlights the importance of aligning instruction with learners' cognitive strengths, particularly the visual-spatial intelligence often observed in deaf students. These frameworks collectively inform the design of the instructional intervention and the development of an inclusive, digital simulation-enhanced model for teaching chemical reactions.

The study is primarily grounded in Game-Based Learning (GBL) theory, which posits that games and digital simulations can create meaningful, engaging, and interactive learning environments. Recent studies define game-based learning as the integration of educational content within game structures that require active learner participation, interaction, and problem-solving **Error! Reference source not found.** In this approach, learners are not passive recipients of information but active participants who construct knowledge through gameplay. Contemporary research further emphasizes that digital game-based learning environments incorporate essential elements such as feedback, challenge, and interactivity, which significantly enhance learner engagement, motivation, and persistence **Error! Reference source not found.** Moreover, studies have shown that game-based learning provides contextualized and authentic learning experiences, allowing learners to apply knowledge in simulated environments that mirror real-world scenarios **Error! Reference source not found.** Empirical evidence also supports its effectiveness in improving learning outcomes, with digital game-based STEM education demonstrating a significant positive effect on students' academic achievement compared to traditional instructional methods **Error! Reference source not found.** These findings collectively affirm that GBL is a powerful pedagogical approach that enhances both cognitive and motivational outcomes by promoting active engagement, immediate feedback, and experiential learning.

In the context of science education, GBL transforms abstract concepts into interactive, manipulable experiences. Digital simulations further enhance this approach by providing visual, interactive, and scaffolded environments that cater to the learning strengths of deaf students, who rely heavily on

visual-spatial modalities. Through digital simulation-enhanced GBL, learners can conduct virtual experiments, observe reactions, and receive real-time feedback, promoting active learning, problem-solving, and engagement.

Constructivist learning theory, emphasizes that learners actively construct knowledge through experiences and interaction with their environment. Learning is not passive; instead, students build meaning through engagement, reflection, and discovery. It highlights the importance of hands-on, experiential learning. For deaf learners, digital simulators allow manipulation of virtual chemical components, enabling comprehension of chemical reactions without reliance on auditory input. The theory stresses discovery learning and scaffolding, advocating for guided learning where learners are supported in uncovering principles independently. Digital simulations act as scaffolds, making abstract scientific concepts concrete and accessible for deaf learners.

Howard Gardner's Multiple Intelligences Theory **Error! Reference source not found.** recognizes that learners possess diverse forms of intelligence, including linguistic, logical-mathematical, spatial, and kinesthetic intelligences. Deaf learners often exhibit strong visual-spatial intelligence, which can be leveraged to enhance science learning.

GBL integrated with digital simulations capitalizes on these visual-spatial strengths by converting abstract chemical processes into interactive visual representations. Learners can observe molecular interactions, manipulate reaction variables, and analyze outcomes, aligning instruction with their cognitive preferences and improving comprehension, motivation, and engagement.

The theoretical framework of this study combines GBL, constructivist principles, and multiple intelligences to inform both the instructional design and the research approach. It posits that interactive digital tools, guided by constructivist and multiple intelligences principles, can enhance understanding of complex scientific concepts among deaf learners. These frameworks collectively support the study's focus on enhancing conceptual understanding of chemical reactions, increasing learner engagement and motivation, promoting active participation in science learning, and developing an inclusive, visual-oriented instructional model tailored to deaf learners.

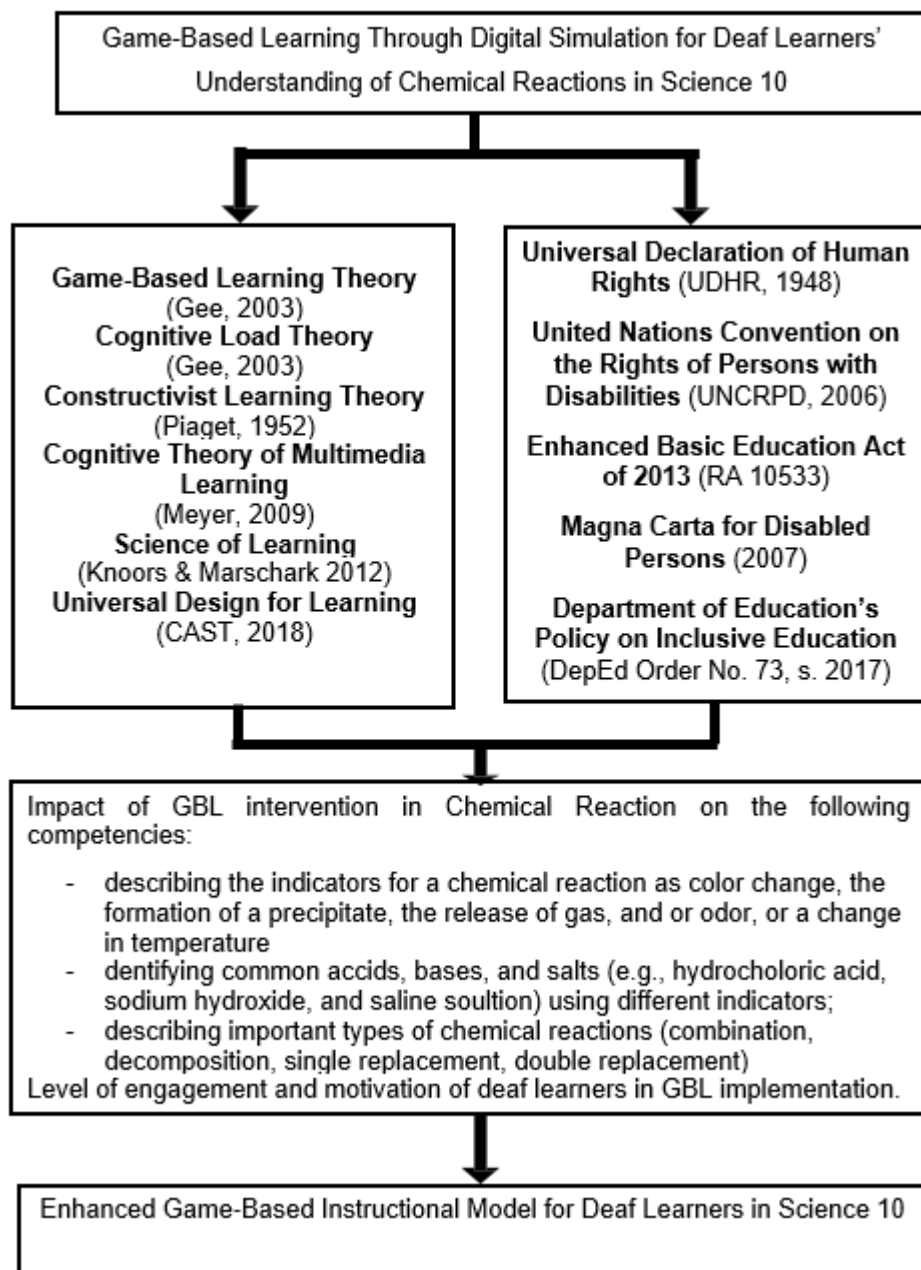
This study is grounded in established educational theories and supported by relevant legal and policy frameworks that affirm learners' rights to inclusive, quality, and learner-centered education. These frameworks collectively justify the integration of GBL with digital simulation to enhance deaf learners' conceptual understanding, engagement, and motivation in science learning, contributing to inclusive educational practices in the Philippines.

The legal and policy foundations of inclusive education in the Philippines provide strong support for ensuring equitable access, quality instruction, and learner-centered approaches for students with disabilities, including deaf learners. At the international level, the Universal Declaration of Human Rights **Error! Reference source not found.** affirms that education is a fundamental human right and should be accessible to all without discrimination. This principle underpins global inclusive education policies and serves as a guiding framework for national legislation. In alignment with this, the United Nations Convention on the Rights of Persons with Disabilities **Error! Reference source not found.** mandates that signatory states, including the Philippines, provide equal access to inclusive, quality education for persons with disabilities. The convention emphasizes the removal of barriers, the provision of reasonable accommodations, and the implementation of learner-centered pedagogies tailored to diverse learning needs (UNCRPD, Art. 24).

The Enhanced Basic Education Act of 2013 **Error! Reference source not found.** institutionalizes the K to 12 curriculum and highlights the importance of differentiated instruction and inclusive practices to support learners with varying abilities and learning preferences. The law mandates that educational programs respond to the unique strengths, interests, and needs of all students, ensuring meaningful engagement and equitable participation in learning (Republic of the Philippines, 2013).

Further reinforcing these rights, Republic Act No. 9442, which amends the Magna Carta for Disabled Persons (2007)**Error! Reference source not found.**, guarantees the right of persons with disabilities to accessible education and requires reasonable accommodations, support services, and specialized instructional strategies to facilitate equitable participation in the classroom.

The Department of Education’s Policy on Inclusive Education (DepEd Order No. 73, s. 2017; DO 44 s.2021) provides the operational framework for implementing inclusive practices in schools. This policy directs schools to offer appropriate instructional approaches, accommodations, and support services that ensure meaningful learning outcomes for learners with disabilities and explicitly encourages the use of learner-centered strategies that align with students’ strengths, interests, and communication needs.



**Figure 1.** A Schematic Presentation of the Theoretical Background of the Study

The schematic presentation illustrates that this study is grounded in four complementary theoretical perspectives that support the use of Game-Based Learning (GBL) through digital simulations for

deaf learners. At the forefront is the Game-Based Learning theory proposed by James Paul Gee (2007), which emphasizes the pedagogical value of interactive, visually engaging environments in enhancing learner motivation, participation, and comprehension. This theory provides the foundation for integrating digital simulations in science instruction, particularly in teaching abstract concepts such as chemical reactions.

The instructional strategy, which involves GBL through digital simulations, serves as the independent variable. Deaf learners interact with dynamic and visually rich simulations that depict chemical processes and provide immediate feedback, thereby promoting experiential and meaningful learning. The dependent variables include learners' conceptual understanding of chemical reactions, as well as their engagement and motivation. Ultimately, the study aims to develop an Enhanced Game-Based Instructional Model tailored to the unique learning needs of deaf learners, aligned with inclusive education principles.

The study is further anchored in the Constructivist Learning Theory of Jean Piaget (1972) and Jerome Bruner (1966), which posits that learners actively construct knowledge through interaction, experience, and reflection. This perspective supports the use of digital simulations as tools for discovery learning, allowing deaf learners to manipulate variables, observe outcomes, and build conceptual understanding through visual and hands-on experiences. Guided instruction and scaffolding play a critical role in helping learners bridge conceptual gaps that may arise due to limited access to auditory information in traditional classroom settings.

In addition, the study draws on the Cognitive Theory of Multimedia Learning developed by Richard E. Mayer **Error! Reference source not found.**, which explains that learners process information through dual channels, primarily visual and auditory, with limited capacity in each. For deaf learners, maximizing visual channels through animations, simulations, and interactive media enhances comprehension and minimizes cognitive overload. This theory reinforces the effectiveness of digital simulations in presenting chemical reactions as dynamic and visually accessible processes.

The study is anchored in the Universal Design for Learning (UDL) framework developed by CAST, which advocates for inclusive instructional design through multiple means of representation, engagement, and expression. UDL ensures that learning environments are accessible and responsive to diverse learners, including those with hearing impairments. The integration of game-based learning and digital simulations aligns with UDL principles by offering flexible, engaging, and visually supported learning experiences that promote active participation and deeper understanding.

These theoretical perspectives collectively provide a strong foundation for the study by linking instructional strategies—GBL and digital simulations—to measurable learner outcomes, including conceptual understanding, engagement, and motivation. The schematic framework demonstrates a coherent and integrated relationship between theoretical underpinnings, instructional design, and expected learning outcomes, thereby establishing a clear rationale for the proposed intervention. The conceptual and policy underpinnings of this study collectively inform an instructional design that is both theoretically sound and practically responsive to the needs of diverse learners. Grounded in Constructivist theory, the study emphasizes interactive, learner-centered approaches that encourage active engagement, inquiry, and critical thinking. Constructivism posits that knowledge is constructed through meaningful experiences, positioning learners as active participants in the learning process rather than passive recipients of information.

The study aligns with the Department of Education's Inclusive Education Policy, which advocates for the removal of barriers to learning and the provision of equitable opportunities for all learners. Inclusive pedagogy ensures that students with varying abilities, including those who are deaf, can meaningfully participate in classroom activities and access curriculum content without discrimination or marginalization. This policy framework is further reinforced by legal instruments such as the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD),

Republic Act 9442, and Republic Act 10533, which collectively mandate equitable educational access and the safeguarding of learners' rights, particularly for those with disabilities.

These theoretical and policy perspectives, the study advocates for the integration of Game-Based Learning (GBL) through digital simulations as an innovative and inclusive instructional strategy. GBL not only supports the development of cognitive and critical thinking skills but also provides an adaptable and engaging learning environment that accommodates the unique needs of deaf learners. The instructional design simultaneously addresses constructivist principles, promotes inclusive participation, and upholds the legal and ethical mandates for equitable education. This framework establishes a coherent rationale for employing technology-mediated, learner-centered approaches to enhance both understanding and academic performance in science among deaf students.

Despite the growing body of research supporting the effectiveness of Game-Based Learning (GBL) in science education, the current study differs in several key aspects. While most previous studies have focused on general science topics or targeted hearing students in single-grade classrooms, this research specifically addresses chemical reactions a topic that requires learners to visualize and predict changes in matter, including reaction types, products, and observable properties. According to the curriculum review conducted by the Department of Education for Science 10 classrooms, understanding chemical reactions is one of the most challenging competencies for learners, particularly those with hearing impairments who rely heavily on visual cues and interactive experiences for comprehension.

Furthermore, this study specifically targets deaf learners in Science 10 classes. By focusing on this population, the study provides an opportunity to evaluate digital simulations not only as a general instructional tool but also as a targeted strategy to enhance understanding and engagement among learners who may struggle with conventional teaching methods. Anchored in the Cognitive Theory of Multimedia Learning of Richard E. Mayer, the use of visual and interactive simulations allows deaf learners to process information more effectively through visual channels, thereby reducing cognitive load and improving comprehension. Moreover, the integration of the Universal Design for Learning framework developed by CAST (2018) ensures that instructional materials are presented in multiple formats, promoting accessibility and inclusivity in science instruction. These frameworks reinforce the need to design learning environments that are responsive to the strengths and needs of deaf learners. The integration of GBL through digital simulations offers interactive, visually rich experiences that align with constructivist principles, allowing deaf learners to actively participate, manipulate virtual experiments, and observe chemical phenomena in ways that are otherwise difficult to achieve in traditional classroom settings. These approaches have been shown to facilitate mastery of complex concepts across various topics. However, there is a notable gap in literature regarding their application specifically for deaf learners in classrooms, particularly in the domain of chemical reactions. The current study seeks to address this gap by investigating how GBL through digital simulations can support deaf learners in understanding chemical reactions and ultimately enhance their academic performance in Science 10.

## **The Problem**

### **Statement of the Problem**

This research examined the case of Game-Based Learning (GBL) implementation through digital simulations for teaching chemical reactions to deaf learners at Naga Special Education Center, City of Naga, Cebu, during the 3rd quarter of SY 2025-2026. The study employed an embedded single-case study design, analyzing both the overall case of GBL implementation and the outcomes of seven (7) deaf learners (Grade 10) as embedded units. The findings informed the development of an Enhanced Game-Based Instructional Model for Deaf Learners.

Specifically, it sought answers to the following questions:

1. How does the Game-Based Learning intervention function within the bounded case of Naga SPED Center's Grade 10 Science classroom?
2. What is the initial level of conceptual understanding of individual deaf learners (embedded units) on chemical reactions before the GBL intervention, in the following competencies:
  - 2.1. Describing the indicators for a chemical reaction as color change, the formation of a precipitate, the release of gas, and/or odor, or a change in temperature;
  - 2.2. Identifying common acids, bases, and salts (e.g., hydrochloric acid, sodium hydroxide, and saline solution) using different indicators; and
  - 2.3. Describing important types of chemical reactions (combination, decomposition, single replacement, double replacement)?
3. What is the final level of conceptual understanding of individual deaf learners (embedded units) on chemical reactions after the GBL intervention on the abovementioned competencies?
4. What is the level of engagement and motivation of deaf learners during GBL implementation?
5. What implementation challenges are encountered by the teacher?
6. What patterns emerge from within-case synthesis and cross-case analysis of the seven embedded units?
7. What Enhanced Game-Based Instructional Model is proposed based on the case findings?

### **Significance of the Study**

This study determined the effectiveness of Game-Based Learning through digital simulations in enhancing deaf learners' understanding of chemical reactions in grade Science 10 are expected to provide valuable insights and benefits to various stakeholders:

**Deaf Learners.** The study enhanced conceptual understanding, engagement, and motivation in learning chemical reactions by leveraging visual-spatial strengths and providing interactive, accessible, and inclusive learning experiences.

**Policy Makers and the Educational Community.** Findings contributed to the promotion and refinement of inclusive education policies, demonstrating practical approaches to ensuring equitable access and meaningful participation for learners with disabilities.

**Researchers and Practitioners.** The study addressed a gap in literature on the use of GBL and digital simulations for deaf learners, providing an evidence-based model for inclusive science instruction and guiding future research in special education and technology-mediated learning.

**School Administrators and Curriculum Planners.** The study informed instructional planning, curriculum development, and professional development programs, supporting the implementation of inclusive, technology-enhanced science education.

**Science Teachers.** Results offered strategies for integrating Game-Based Learning and digital simulations into classrooms, providing guidance on scaffolding abstract concepts and addressing the unique needs of deaf learners.

### **Research Methodology**

This section discussed the research methodology. It contains the research design, the research flow, research environment, research respondents, research instruments, data gathering procedures, statistical treatment of data, scoring procedures, and definition of terms.

### **Research Design**

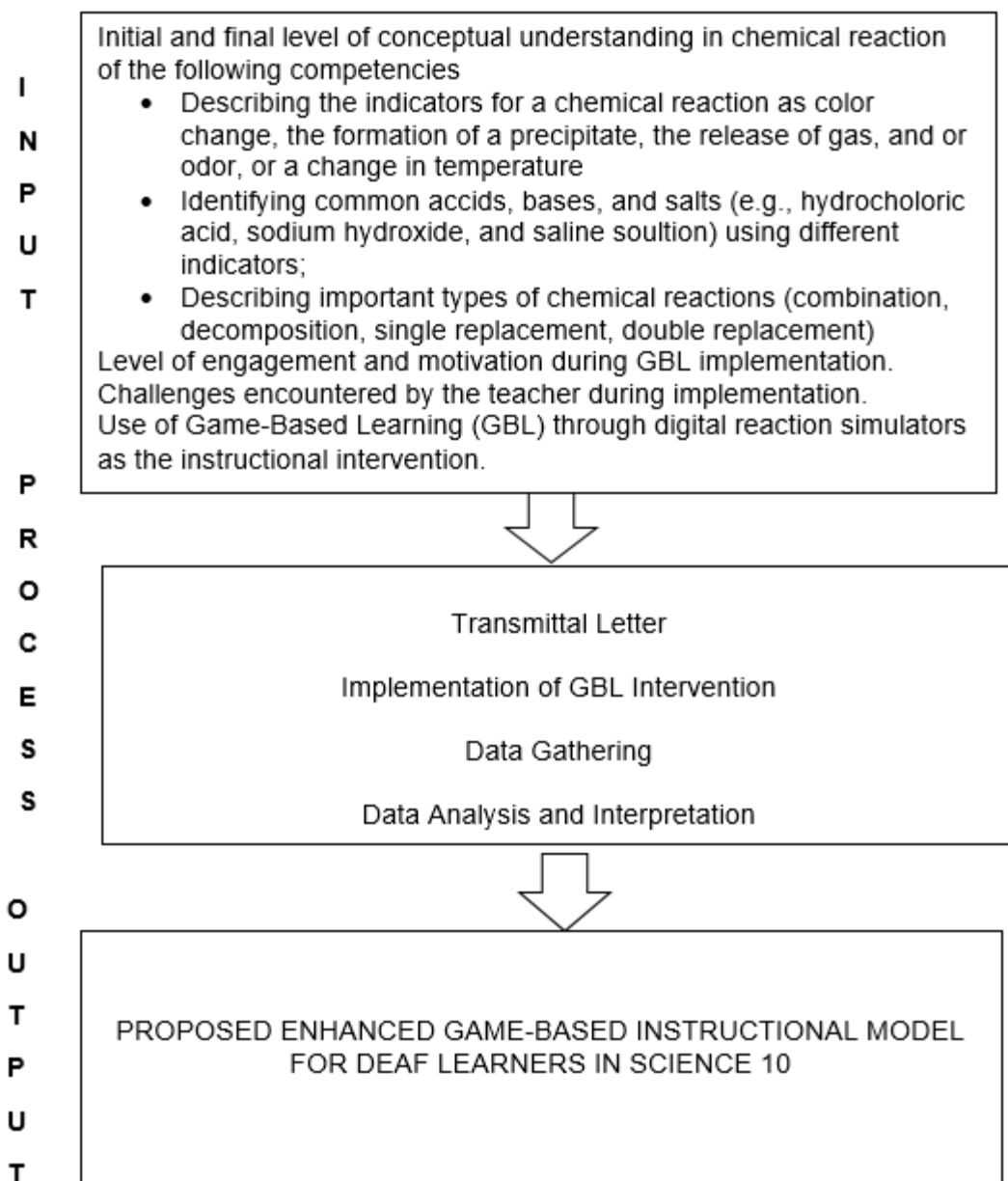
This study employed an embedded single-case study design with quantitative emphasis. The case is the implementation of game-based learning through digital simulations at Naga SPED Center. The seven deaf learners in Grades 10 serve as embedded units of analysis within this bounded case. The design utilizes pre-test and post-test measurements, descriptive statistics, individual learner profiles, and qualitative observations to provide an in-depth examination of how GBL enhances understanding of chemical reactions among deaf learners in this specific SPED context.

### **Research Flow**

The Input-Process-Output (IPO) model suited for this study well. The input includes the use of game-based learning (GBL) as the independent variable and deaf learners' understanding of chemical reactions as the dependent variable. It also considers the theories of constructivism and multiple intelligences as the foundation of the study.

The process involved the administration of a pre-test to assess learners' initial understanding, the implementation of GBL through digital reaction simulators, and the conduct of a post-test to measure learning gains. Data are then statistically analyzed to determine significance.

The output of the study is the Enhanced Game-Based Instructional Model for Deaf Learners in Science, which aims to improve comprehension, engagement, and inclusivity in science instruction.



**Figure 2.** Flow of the Research Study

### Research Environment

This study was conducted at Naga Special Education (SPED) Center, located in the City of Naga, Cebu, Philippines. The school is a public institution that caters to learners with diverse needs, including those who are deaf, visually impaired, intellectually disabled, and learners with autism. It serves as the division's primary center for implementing inclusive and special education programs, ensuring that all children, regardless of their disabilities, have access to quality and equitable education.

The Naga SPED Center has a self-contained multi-grade class for deaf learners, equipped with basic learning materials and supported by teachers trained in Filipino Sign Language (FSL) and inclusive instructional strategies. The classrooms are designed to promote a visual learning environment, integrating multimedia and visual aids to support learners' comprehension.

This setting provides an ideal environment for the conduct of the study since it focuses on the use of Game-Based Learning (GBL) through digital simulators in teaching chemical reactions, a topic

often challenging for deaf learners due to its abstract nature and reliance on spoken explanations. The school's commitment to inclusive education and technology integration makes it a suitable venue to explore innovative approaches that aim to enhance the learning experience and academic performance of deaf students.



**Figure 3.** Location Map of the Research Environment

### Research Respondents

The respondents of this study are the Grade 10 deaf learners enrolled at Naga Special Education Center, City of Naga, Cebu, during the School Year 2025–2026. The class consists of students with hearing impairments who communicate primarily through Filipino Sign Language (FSL). They are taught in a self-contained classroom under the supervision of a licensed SPED teacher.

The selection of respondents was done through total enumeration, as all Grade 10 deaf learners of the school will participate in the study. This approach ensures that the findings accurately represent the entire group, considering the small population size typical of SPED classes. The respondents are selected because they have already taken foundational science subjects and are capable of performing the experimental activities related to chemical reactions.

**Table 1.** Frequency Distribution of Respondents

| Respondents | Total Population | % | % | Total |
|-------------|------------------|---|---|-------|
|-------------|------------------|---|---|-------|

|          |      |        |             |               |   |
|----------|------|--------|-------------|---------------|---|
|          | Male | Female | <b>Male</b> | <b>Female</b> |   |
| Grade 10 | 4    | 3      | 57%         | 43%           | 7 |

## Research Instrument

The primary instrument used in this study is a pre-test and post-test assessment developed through a collaborative process involving curriculum mapping and technological assistance. It was designed to measure the learners' conceptual understanding of chemical reactions—specifically focusing on reaction indicators, identifying substances, and types of chemical reactions—before and after exposure to PhET digital simulations. To ensure the instrument is accessible to deaf learners, the test items are translated into simplified English and paired with Filipino Sign Language (FSL) visual prompts to bypass linguistic bottlenecks.

In addition to the performance tests, a Behavioral Engagement Observation Rubric and a Learner Perception Survey are utilized. These instruments measure the "Always Observed" to "Never Observed" frequency of engagement and the "Strongly Agree" to "Strongly Disagree" perception of the GBL intervention. All instruments were validated by a panel of Science experts and SPED specialists to ensure content validity and reliability for learners with hearing impairments.

## Data-gathering Procedure

Prior to the conduct of the study, a letter of permission was sought from the Schools Division Superintendent and the Supervisor in-charge of Naga Special Education Center to allow the researcher to conduct the study. Once approved, the researcher coordinated with the assigned Science teacher of the deaf class for scheduling and implementation.

The data-gathering process followed a four-stage sequence. First, a Pre-test was administered to establish a baseline of the learners' prior knowledge. Second, the GBL Intervention was implemented, where learners engaged in 60-minute sessions using digital simulators. During these sessions, the researcher utilized the observation rubric to document behavioral engagement. Third, a Post-test was conducted to measure the cognitive gains. Finally, the learner perception survey was administered to capture the students' motivation and attitudes toward the digital tools.

Data were collected and tabulated. The survey on learners' engagement and motivation was distributed and retrieved after the intervention period. All gathered data were treated with confidentiality and ethical considerations following the DepEd research guidelines.

## Statistical Treatment

The data collected from the pretest, posttest, and survey instruments were processed and analyzed using the following statistical methods:

1. Mean and Standard Deviation. These were calculated to represent the central tendency and the dispersion of the students' scores. This determined the average improvement in conceptual understanding and the consistency of the learners' performance across different competencies.
2. Frequency and Percentage Distribution. This was used to categorize the learners into "Gain Profiles" (High, Moderate, and Lower Gainers). This helped identify how many students achieved significant progress regardless of their initial independence levels.
3. Weighted Mean (Likert Scale). For the engagement rubric and perception survey, a 4-point Likert scale was used to quantify the results. A mean of 3.51 – 4.00 was interpreted as "Strongly Agree" or "Always Observed," providing a clear numerical value for the learners' high levels of motivation and focus.
4. Comparative Analysis of Mean Gains. Instead of a standard t-Test for large samples, this study utilized a descriptive comparison of mean scores and individual gain analysis suitable for a small, specialized group (N=7). This allowed the researcher to track individual shifts in the

frequency distribution and identify the avoidance of "ceiling effects" in high-performing learners.

5. Thematic Analysis. The qualitative data from the open-ended survey questions was analyzed through thematic analysis. This involves reviewing the responses to identify, categorize, and interpret common themes, patterns, and insights related to students' challenges and experiences when using the Game-Based Learning through Digital Simulator.

### Scoring Procedures

The scoring of the instruments followed the procedures described below to ensure consistent and accurate measurement of students' performance and perceptions.

1. Multiple-Choice Pretest and Posttest. Each of the three science competencies was assessed using 10 multiple-choice items, for a total of 30 items in the test. Each correct answer was given one (1) point, while incorrect or unanswered items will receive zero (0) point. The raw score for each competency was calculated out of 10, then converted into a percentage score by dividing the raw score by 10 and multiplying by 100.

To determine the performance level of the students per competency, the following rating scale was applied:

| Raw Score | Category                      | Verbal Description                                |
|-----------|-------------------------------|---|
| 9-10      | Mastered                      | Learner's performance level is between 96% - 100% |
| 7-8       | Closely Approximating Mastery | Learner's performance level is between 86% - 95%  |
| 5-6       | Moving Towards Mastery        | Learner's performance level is between 66% - 85%  |
| 3-4       | Average Mastery               | Learner's performance level is between 35% - 65%  |
| 0-2       | Low Mastery                   | Learner's performance level is between 16% - 34%  |

This rating scale is an adaptation of the assessment framework stipulated in DepEd Order No. 8, s. 2015, Policy Guidelines on Classroom Assessment for the K to 12 Basic Education Program. While the performance descriptors and their corresponding pedagogical intent remain consistent with DepEd standards, modifications were implemented to suit the requirements of this specific 10-item instrument. The standard percentage-based grading system was condensed into a 10-point raw score scale to facilitate immediate evaluation of short-form assessments. Additionally, the official percentage thresholds were recalibrated to map directly to these raw score intervals, ensuring that the learner's performance level is accurately categorized without the necessity of manual percentage conversion. These adjustments streamline the feedback process while maintaining the integrity of the original grading policy.

2. Likert-Scale Survey. The survey consists of 10 statements; each rated on a 4-point scale:

For each participant, responses will be assigned the corresponding numerical values. The scores for each item will be summed and averaged to calculate the mean rating. The mean scores were interpreted using the following scale:

| Mean Range  | Category       | Verbal Description                       |
|-------------|----------------|--|
| 3.26 – 4.00 | Strongly Agree | Indicates a very high level of agreement |
| 2.51 – 3.25 | Agree          | Indicates a very high level of agreement |
| 1.76 – 2.50 | Disagree       | Indicates a low level of agreement       |

|             |                   |                                       |
|-------------|-------------------|---------------------------------------|
| 1.00 – 1.75 | Strongly Disagree | Indicates a very low level of agreeem |
|-------------|-------------------|---------------------------------------|

This scoring quantified the students' perceptions after using the Proposed Game-Based Learning.

### Definition Terms

To preclude ambiguity and uncertainly, the following terminologies are defined operationally:

**Chemical Reactions.** This refers to the cognitive and conceptual comprehension of deaf learners regarding the processes involved in chemical changes, specifically covering indicators of reactions, identification of acids, bases, and salts, and the four major types of chemical reactions (combination, decomposition, single replacement, and double replacement) .

**Deaf Learners.** This refers to the Grade 10 students enrolled in the self-contained SPED class at Naga Special Education Center who communicate primarily through Filipino Sign Language (FSL) and are the central participants of this study.

**Digital Simulations.** These are interactive, computer-based models (specifically PhET Interactive Simulations) that allow learners to visualize molecular interactions, manipulate variables, and observe scientific phenomena in a virtual environment to reduce the "split-attention effect".

**Filipino Sign Language (FSL).** This refers to the visual-spatial language mandated by law as the medium of instruction for deaf learners in the Philippines, used in this study to translate scientific competencies and facilitate classroom communication.

**Final Level of Conceptual Understanding.** This refers to the post-intervention cognitive state of the learners after engaging with the PhET digital simulations and game-based tasks. It is measured through the post-test scores and characterizes the extent to which the learners have mastered the competencies in Science 10. This level reflects the effectiveness of the visual-spatial discovery approach in bridging previous gaps in the learners' comprehension of abstract scientific processes.

**Game-Based Learning (GBL).** An instructional approach that uses digital games and simulation tools to transform abstract Science lessons into interactive and experiential learning activities that provide immediate feedback and foster intrinsic motivation.

**Inclusive Education.** A pedagogical framework and policy environment that ensures equitable access to quality education for all students, regardless of disability, through appropriate accommodations and learner-centered strategies .

**Initial Level of Conceptual Understanding.** This refers to the baseline knowledge and cognitive grasp of Grade 10 deaf learners regarding chemical reactions prior to the integration of game-based digital simulations. This level is quantitatively measured through the pre-test scores, representing the learners' existing schemas and their ability to identify chemical indicators and reaction types using traditional instructional backgrounds.

**Learner Engagement.** This refers to the degree of attention, curiosity, and interest that deaf learners show during the GBL intervention, measured through behavioral indicators such as sustained focus on simulation displays and active manipulation of variables .

**Motivation.** This refers to the learners' internal drive and positive affective response toward learning Science 10, characterized by visible excitement, persistence in tasks, and a self-reported desire to use digital tools in future lessons.

**Naga Special Education (SPED) Center.** This refers to a public educational institution located in the City of Naga, Cebu, Philippines, which serves as the primary division center for implementing inclusive and special education programs . In this study, it is the specific research environment where Grade 10 deaf learners are taught in a self-contained, visual learning-oriented classroom

equipped with multimedia resources and supported by teachers trained in Filipino Sign Language (FSL)

**Science of Learning for Deaf Students.** The theoretical framework which posits that deaf learners possess unique cognitive architectures—specifically visual-spatial strengths—that require instruction to bypass traditional auditory-based "linguistic bottlenecks" .

**Visual-Spatial Intelligence.** A cognitive strength often observed in deaf learners where information is processed more effectively through simultaneous visual channels and mental image rather than sequential auditory input.

## **Chapter 2**

### **Presentation, Analysis, and Interpretation of Data**

This chapter presents the findings of the embedded single-case study examining the implementation of Game-Based Learning (GBL) through digital simulations for teaching chemical reactions to deaf learners at Naga Special Education Center. The analysis follows a dual-level approach, focusing on both the overall case of GBL implementation within the SPED context and the embedded units of analysis or individual learner outcomes. Data are presented and analyzed using descriptive statistics, individual learner profiles, cross-case pattern analysis, and qualitative classroom observations. This mixed-methods approach provides a comprehensive understanding of the effectiveness, accessibility, and instructional feasibility of GBL in supporting deaf learners' engagement and learning in chemistry.

#### **Game-Based Learning Implementation**

The case under investigation is the implementation of Game-Based Learning through digital simulations (specifically, PhET Interactive Simulations for Chemical Reactions) at Naga Special Education Center during the third quarter of School Year 2025-2026. The bounded case comprises seven (7) deaf learners from Grade 10, one SPED-certified science teacher, and the specialized instructional environment of a self-contained classroom equipped with tablets and Filipino Sign Language (FSL) support.

#### **Case Characteristics**

- Setting: Self-contained multi-grade classroom (Grade 10) at Naga SPED Center, City of Naga, Cebu
- Population: Eight (8) deaf learners with varying degrees of hearing impairment, all using Filipino Sign Language (FSL) as primary communication mode
- Intervention Duration: Six (6) weeks, with three (3) 60-minute sessions per week using digital simulators
- Technology Used: PhET Interactive Simulations (Chemical Reactions module) on tablets with FSL captioning
- Content Focus: Chemical reactions indicators, acids-bases-salts identification, and types of chemical reactions

#### **Learner Profile and Context**

Learner L1 (pseudonym: FE\_LA) is a 19-year-old female deaf learner enrolled in Grade 10 at Naga Special Education Center. She presents with profound bilateral sensorineural hearing loss (>90 dB HL in both ears), diagnosed at age 2 following a high fever and subsequent auditory screening. L1 communicates primarily through American Sign Language (ASL), which she acquired at age 5 upon enrollment in a specialized early intervention program.

Educational Background: L1 has been in the SPED system since kindergarten and demonstrates grade-appropriate literacy skills in Filipino and English, though with noted delays in academic vocabulary, particularly in science and mathematics domains (reading level assessed at Grade 7 equivalent). She exhibits moderate independence during learning tasks, requiring occasional teacher scaffolding for complex multi-step activities but capable of sustained self-directed work with clear visual instructions.

Baseline Characteristics Relevant to GBL Intervention: Prior to the study, L1 had limited exposure to technology-enhanced science instruction, with most previous chemistry lessons delivered through textbook reading, sign language-interpreted lectures, and static diagrams. Her learning profile indicates strong visual-spatial processing skills, as evidenced by performance on non-verbal reasoning tasks, but struggles with abstract conceptual understanding when concepts are presented solely through text or sign language without visual referents.

Learner L2 (pseudonym: JA\_TA) is an 18-year-old male deaf learner enrolled in Grade 10 at Naga Special Education Center. He presents with moderate to severe bilateral sensorineural hearing loss (56-70 dB HL in both ears), diagnosed at age 3 through routine developmental screening revealing delayed auditory responses. L2 communicates primarily through Filipino Sign Language (FSL), which he acquired at age 4 through family-based sign language instruction and formal SPED enrollment.

Educational Background: L2 has been enrolled in SPED programs since preschool and demonstrates strong literacy skills in Filipino (grade-level equivalent) with developing English proficiency (Grade 8 equivalent). Academic performance consistently above average in mathematics and science courses. He exhibits high independence during learning tasks, requiring minimal teacher scaffolding and demonstrating strong self-directed learning capabilities, metacognitive awareness, and peer leadership qualities.

Baseline Characteristics Relevant to GBL Intervention: Prior to the study, L2 had moderate exposure to technology-enhanced instruction, having participated in previous computer-based mathematics interventions and demonstrated quick adaptation to new educational software platforms. His learning profile indicates exceptional visual-spatial processing coupled with strong analytical reasoning skills, particularly evident in pattern recognition and logical sequencing tasks. He demonstrates ability to transfer learning across contexts and apply conceptual understanding to novel problem-solving situations.

Learner L3 (pseudonym: EM\_ZA) is a 16-year-old female deaf learner enrolled in Grade 10 at Naga Special Education Center. She presents with moderate to severe bilateral sensorineural hearing loss (60-75 dB HL in both ears), diagnosed at 18 months following parental concerns about unresponsiveness to environmental sounds and delayed speech development. L3 communicates primarily through Filipino Sign Language (FSL), which she acquired at age 3 through intensive early intervention services and family sign language training.

Educational Background: L3 has attended Naga SPED Center since Grade 1 and demonstrates exceptionally strong literacy skills in both Filipino and English (grade-level to above-grade-level performance), with particular strength in reading comprehension and written expression. She consistently achieves highest academic performance in her cohort. L3 exhibits high independence during learning tasks, demonstrating advanced self-regulation, goal-setting, and independent study habits. She requires minimal teacher intervention and frequently assists peers with academic challenges.

Baseline Characteristics Relevant to GBL Intervention: Prior to the study, L3 had moderate to high exposure to educational technology, including previous use of interactive e-books, educational apps, and online learning platforms. She demonstrates comfort with tablet navigation and digital interfaces. Her learning profile indicates strong visual-spatial processing combined with exceptional

verbal-linguistic intelligence (as measured through sign language proficiency and written expression), sophisticated conceptual understanding, critical thinking skills, and ability to make abstract connections across disciplines.

Learner L4 (pseudonym: JE\_ER) is a 15-year-old male deaf learner enrolled in Grade 10 at Naga Special Education Center. He presents with severe to profound bilateral sensorineural hearing loss (75-90 dB HL in both ears), diagnosed at 1 year following failed newborn hearing screening and follow-up audiological evaluation. L4 communicates primarily through American Sign Language (ASL), with functional proficiency in Filipino Sign Language (FSL), acquired at age 2 through family ASL instruction (parents are Deaf), with FSL acquired upon school enrollment at age 6.

Educational Background: L4 comes from a Deaf family (both parents Deaf, one older Deaf sibling) and has been immersed in Deaf culture since birth. He demonstrates grade-appropriate literacy in Filipino and English (Grade 9 equivalent), with stronger receptive than expressive written language skills. L4 exhibits high independence during learning tasks, demonstrating strong collaborative skills and comfort seeking peer support. He benefits from structured activities with clear objectives but can work autonomously when needed.

Baseline Characteristics Relevant to GBL Intervention: Prior to the study, L4 had moderate exposure to technology through family use of video phones, texting, and social media. Limited prior exposure to educational simulations but comfortable with general tablet/smartphone navigation. His learning profile indicates strong social-cognitive skills and collaborative learning orientation, demonstrating particular strength when working with peers. Visual-spatial processing adequate, with relative strength in hands-on, kinesthetic learning experiences. He benefits from social scaffolding and peer explanation of concepts.

Learner L5 (pseudonym: AN\_GE) is a 17-year-old female deaf learner enrolled in Grade 10 at Naga Special Education Center. She presents with profound bilateral sensorineural hearing loss (>90 dB HL in both ears), diagnosed at age 7 following ototoxic medication (aminoglycoside antibiotics) prescribed for severe infection, resulting in acquired deafness after early childhood hearing loss. L5 communicates primarily through Filipino Sign Language (FSL), which she acquired at age 8 following late diagnosis and subsequent SPED enrollment, experiencing delayed language acquisition due to late identification of hearing loss.

Educational Background: L5 transferred to SPED system in Grade 3 after struggling in mainstream inclusion settings. She demonstrates below-grade-level literacy skills in Filipino and English (Grade 4-5 equivalent) due to delayed language exposure and interrupted early education. She receives supplemental reading intervention services. L5 exhibits low to moderate independence during learning tasks, requiring substantial teacher scaffolding, frequent check-ins, and explicit step-by-step guidance for multi-step activities. She benefits from one-on-one instruction and reduced cognitive load.

Baseline Characteristics Relevant to GBL Intervention: Prior to the study, L5 had minimal exposure to educational technology. Family has limited access to digital devices at home, and she required extensive orientation to tablet operation and simulation navigation. Her learning profile indicates developing visual-spatial processing skills with particular challenges in abstract reasoning and conceptual transfer. She demonstrates stronger performance on concrete, procedural tasks compared to conceptual understanding, with positive attitude toward learning despite academic struggles and high motivation when provided appropriate supports.

Learner L6 (pseudonym: CL\_BA) is a 15-year-old female deaf learner enrolled in Grade 10 at Naga Special Education Center. She presents with profound bilateral sensorineural hearing loss (>90 dB HL in both ears), diagnosed at 6 months following parental concerns and delayed speech milestones, later attributed to congenital cytomegalovirus (CMV) infection. L6 communicates primarily through American Sign Language (ASL), which she acquired at age 7 upon SPED

enrollment, with some residual speech from early hearing period that she occasionally uses for familiar words.

**Educational Background:** L6 has been enrolled in SPED since Grade 1 and demonstrates grade-appropriate to slightly-below-grade literacy skills in Filipino and English (Grade 7-8 equivalent). She shows stronger performance in science and hands-on subjects compared to language-heavy humanities courses. L6 exhibits moderate independence during learning tasks, demonstrating increased self-direction over time but still benefiting from periodic teacher check-ins and clarification. She prefers structured activities with clear success criteria.

**Baseline Characteristics Relevant to GBL Intervention:** Prior to the study, L6 had moderate exposure to technology through family tablet use for entertainment (videos, games) and some prior experience with educational apps for math practice. She is generally comfortable with touch-screen interfaces. Her learning profile indicates strong visual-spatial processing with particular aptitude for science content. She demonstrates hands-on learning preference and benefits from concrete examples and visual representations, with high intrinsic motivation for science learning and positive attitude toward novel instructional approaches.

**Learner L7 (pseudonym: OM\_CA)** is a 15-year-old male deaf learner enrolled in Grade 10 at Naga Special Education Center. He presents with profound bilateral sensorineural hearing loss (>90 dB HL in both ears), diagnosed at 9 months following traumatic head injury from motorcycle accident, resulting in acquired profound hearing loss. L7 communicates primarily through Filipino Sign Language (FSL), which he acquired at age 10 following diagnosis and SPED placement, experiencing a relatively late language deprivation period though he had developed spoken Filipino prior to hearing loss.

**Educational Background:** L7 attended mainstream schools through Grade 3 before accident, then transitioned to SPED system in Grade 4. He demonstrates grade-appropriate literacy skills in Filipino (maintained from pre-accident education) but struggles with new academic content requiring sign language instruction. Reading level Grade 8 equivalent. L7 exhibits high independence during learning tasks, demonstrating strong self-direction and task persistence. However, his independence is sometimes coupled with reluctance to seek help when needed, potentially limiting learning optimization.

**Baseline Characteristics Relevant to GBL Intervention:** Prior to the study, L7 had high exposure to technology, with strong familiarity with smartphones, social media, and gaming platforms. He is comfortable with technology but had limited prior exposure to educational simulations specifically. His learning profile indicates adequate visual-spatial processing, though assessment suggests this may not be as developed as typically observed in early-onset deaf individuals. He demonstrates strong procedural memory and ability to follow sequential steps, but may have more difficulty with conceptual abstraction compared to peers. The late-onset nature of his deafness may influence learning patterns differently than congenital deafness.

### **Level of conceptual understanding of deaf learners on chemical reactions**

Table 2 presents individual learner performance profiles, showing pre-test scores, post-test scores, gain scores, and individual effect sizes. This embedded units analysis reveals patterns of response to the GBL intervention across the eight deaf learners.

**Table 2.** Initial Level of Conceptual Understanding of Deaf Learners on Chemical Reaction Before Using GBL

| <b>Learner</b>         | <b>Comptency 1</b><br><i>describin<br/>g the<br/>indicator<br/>s for a<br/>chemical<br/>reaction<br/>as color<br/>change,<br/>the<br/>formation<br/>of a<br/>precipitat<br/>e, the<br/>release of<br/>gas,<br/>and/or<br/>odor, or<br/>change in<br/>temperat<br/>ure (10<br/>items)</i> | <b>Comptency 2</b><br><i>identifying<br/>common acids,<br/>bases, and salts<br/>(e.g.,<br/>hydrochloric<br/>acid, sodium<br/>hydroxide, and<br/>saline solution)<br/>using different<br/>indicators (10<br/>items)</i> | <b>Comptency 3</b><br><i>describing<br/>important<br/>types of<br/>chemical<br/>reactions<br/>(combination,<br/>decomposition,<br/>single<br/>replacement,<br/>double<br/>replacement)<br/>10 items</i> | <b>Total<br/>(30)</b> | <b>Equivalent<br/>/Category</b>              |
|------------------------|--|--|---|-----------------------|--|
| L1                     | 5  | 3  | 6   | 14                    | Average Mastery                              |
| L2                     | 3  | 7  | 9   | 19                    | Moving Towards<br>Mastery                    |
| L3                     | 6  | 8  | 8   | 22                    | Closely<br>Approximating<br>Mastery          |
| L4                     | 4  | 7  | 7   | 18                    | Moving Towards<br>Mastery                    |
| L5                     | 3  | 2  | 7   | 12                    | Average Mastery<br>Moving Towards<br>Mastery |
| L6                     | 3  | 6  | 7   | 16                    | Moving Towards<br>Mastery                    |
| L7                     | 4  | 7  | 8   | 19                    | Moving Towards<br>Mastery                    |
| <b>Score<br/>Range</b> | <b>F</b>   | <b>Pecrcentage</b>   | <b>Meand (SD)</b>   |                       | <b>Equivalent/<br/>Category</b>              |
| 25-30                  | 0  | 0%   | -   |                       | -  |
| 19-24                  | 3  | 42.86%   | 17.14   |                       | Moving Towards<br>Mastery                    |
| 13-18                  | 3  | 42.86%   | 17.14   |                       | Moving Towards<br>Mastery                    |
| 7-12                   | 1  | 14.28%   | 3.34  |                       | Moving Towards<br>Mastery                    |
| 0-6                    | 0  | 0%   |   |                       |  |

|  |  |  |  |  |                 |
|--|--|--|--|--|-----------------|
|  |  |  |  |  | Average Mastery |
|  |  |  |  |  | -               |

*Legend: 9-10 (Mastered, 96%-100%); 7-8 (Closely Approximating Mastery, 86%-95%); 5-6 (Moving Towards Mastery, 66%-85%), 3-4 (Average Mastery, 35%-65%), 0-2 (Low Mastery, 16%-34%).*

Table 2 presents the pre-test performance of seven deaf learners (embedded units) across three chemical reactions competencies, establishing baseline understanding prior to the GBL intervention. The results indicate a varied starting point, with overall group performance falling into the Moving Towards Mastery category ( Mean = 17.14, SD = 3.34 ), yet revealing significant disparities in mastery across the specific domains of chemistry.

The group demonstrated their lowest baseline performance in Competency 1 (Indicators of Chemical Reactions), where the group average reflected Average Mastery. A majority of the learners (71.43%) scored within the 3–4 range, and notably, no learner reached the "Closely Approximating Mastery" or "Mastered" levels. This suggests a significant gap in the learners' ability to conceptually link observable phenomena—such as precipitate formation or temperature changes—to the underlying chemical process. This finding is consistent with existing literature regarding Deaf education, which notes that abstract conceptual explanations often pose a greater challenge than concrete identification tasks, necessitating more robust visual or hands-on scaffolding to bridge the gap between observation and inference.

This finding aligns with research documenting that deaf learners often experience gaps in science concept development due to limited access to incidental learning opportunities and auditory-based laboratory demonstrations common in mainstream classrooms. The abstract nature of explaining WHY observable changes indicate chemical reactions—beyond simply recognizing that changes occurred—requires conceptual understanding typically developed through explicit instruction and hands-on experimentation, opportunities that may have been limited in learners' prior science education.

Performance on acid-base identification showed the highest degree of internal variability (SD = 2.12). While the majority of learners (57.14%) achieved scores in the Closely Approximating Mastery range, the presence of a learner in the Low Mastery category (0–2 points) highlights a fragmented baseline. This spread likely reflects unequal prior exposure to these concepts in earlier science education or varying degrees of incidental learning related to household chemicals. The relatively higher success in this area compared to Competency 1 may be attributed to the concrete, color-coded nature of pH indicators, which aligns with the visual learning strengths of Deaf students.

The relatively higher mean performance on Competency 2 compared to Competency 1 may reflect the concrete, observable nature of indicator tests (litmus paper color changes, pH paper readings) compared to the more abstract conceptual understanding required for Competency 1. Research on deaf learners' science understanding indicates that concrete, visually-based tasks are often more accessible than abstract conceptual explanations. However, the presence of one learner in the Low Mastery category (0-2 points) signals substantial foundational gaps requiring intensive support.

Competency 3 emerged as the area of greatest strength, with the group achieving a level of Moving Towards Mastery. Most learners (71.43%) scored in the 7–8 range, and one learner achieved full Mastery. The consistency of these high scores (SD = 0.90) suggests that the task of classifying reactions—which relies heavily on visual pattern recognition and structural matching—is highly accessible to this cohort. This reinforces the theoretical premise of the study: that instructional modalities emphasizing visual-spatial logic, such as those found in Game-Based Learning, leverage the documented cognitive strengths of Deaf learners.

The substantially higher performance on reaction type classification compared to Competencies 1 and 2 likely reflects the pattern-recognition nature of this task. Identifying reaction types (synthesis, decomposition, single replacement, double replacement) based on visual structural formulas emphasizes spatial pattern matching—a documented cognitive strength among deaf individuals. This aligns with Gardner's (1983) Multiple Intelligences Theory, specifically visual-spatial intelligence, and provides empirical support for the theoretical rationale guiding the GBL intervention: that visual-spatial instructional modalities should enhance learning for deaf learners.

Moreover, these findings underscore the importance of aligning instructional design with the cognitive and perceptual strengths of deaf learners, particularly through visually mediated and interactive learning environments. The variation in performance across competencies further suggests that targeted scaffolding is necessary for abstract conceptual domains, while more advanced visual classification skills may be leveraged as entry points for deeper conceptual development during the intervention.

The ascending performance pattern suggests that learners found visually-based classification tasks more accessible than conceptual understanding or abstract acid-base chemistry. This baseline pattern has implications for intervention design: Competency 1, with lowest baseline, represents the greatest opportunity for growth (largest "zone" for learning), while Competency 3's higher baseline may constrain absolute gains due to ceiling effects, though percentage growth and mastery category advancement remain possible.

In addition, the observed baseline pattern highlights the instructional value of using learners' existing strengths in visual-spatial reasoning as a foundation for introducing more complex scientific concepts. By anchoring instruction on competencies where learners already demonstrate relative success, the intervention can progressively scaffold toward higher-order conceptual understanding, thereby reducing cognitive overload and improving knowledge retention throughout the Game-Based Learning process.

The pre-test results establish that the seven embedded units entered the GBL intervention with heterogeneous baseline knowledge (individual total scores ranging from 12-22 out of 30 points) but shared patterns of relative strength in visual-spatial tasks. These baseline characteristics frame the interpretation of post-intervention outcomes (RQ3, Table 2) and inform the design of differentiated supports in the Enhanced Model (RQ7).

### **Level of conceptual understanding of deaf learners on chemical reactions after using GBL**

Table 3 presents post-test performance following the six-week GBL intervention. Comparing Table 2 to Table 3 (pre-test), upward shifts in frequency distributions, mean scores, and mastery categories are evident across all three competencies, indicating positive intervention effects. Comparing Tables 3 (RQ2: pre-test) and 2 (RQ3: post-test) enables assessment of the GBL intervention's impact on conceptual understanding.

This section presents case-level (aggregate) evidence of change, followed by individual embedded unit analysis (individual case studies). Effect sizes are calculated using Cohen's *d*, interpreted as small ( $d = 0.20$ ), medium ( $d = 0.50$ ), large ( $d = 0.80$ ), or very large ( $d \geq 1.20$ ) effects.

Competency 1 demonstrated a substantial performance gain, achieving a post-intervention mean of 5.57. The frequency distribution shifted significantly: pre-intervention, the majority of learners scored in the lower tiers; post-intervention, the modal category moved to the 5-6 range (71.43% of learners), signifying a shift toward the Moving Towards Mastery level. The very large effect size ( $d = 1.43$ ) exceeds conventional thresholds for educational interventions and indicates exceptional practical significance.

This improvement in understanding chemical reaction indicators aligns with the theoretical rationale for visual-spatial instruction. The PhET simulations

**Table 3.** Level of conceptual understanding of deaf learners on chemical reactions after using GBL

| <b>Learner</b>     | <b>Comptency 1</b><br><i>describing the indicators for a chemical reaction as color change, the formation of a precipitate, the release of gas, and/or odor, or change in temperature (10 items)</i> | <b>Comptency 2</b><br><i>identifying common acids, bases, and salts (e.g., hydrochloric acid, sodium hydroxide, and saline solution) using different indicators (10 items)</i> | <b>Comptency 3</b><br><i>describing important types of chemical reactions (combination, decomposition, single replacement, double replacement) 10 items</i> | <b>Total (30)</b> | <b>Equivalent/Category</b>    |
|--------------------|--|--|---|-------------------|-------------------------------|
| L1                 | 5  | 5  | 7   | 17                | Moving Towards Mastery        |
| L2                 | 6  | 8  | 10  | 24                | Closely Approximating Mastery |
| L3                 | 7  | 8  | 8   | 23                | Moving Towards Mastery        |
| L4                 | 6  | 7  | 8   | 21                | Moving Towards Mastery        |
| L5                 | 3  | 4  | 7   | 14                | Average Mastery               |
| L6                 | 6  | 6  | 8   | 20                | Moving Towards Mastery        |
| L7                 | 6  | 7  | 8   | 21                | Moving Towards Mastery        |
| <b>Score Range</b> | <b>F</b>   | <b>Percentage</b>  | <b>Meand (SD)</b>   |                   | <b>Equivalent/Category</b>    |
| 25-30              | 0  | 0%   | -   |                   | -                             |
| 19-24              | 5  | 71.43%   | -   |                   | Moving Towards Mastery        |
| 13-18              | 2  | 28.57%   | -   |                   | Moving Towards Mastery        |
| 7-12               | 0  | 0%   |   |                   | Average Mastery               |
| 0-6                | 0  | 0%   | 20.00(3.46)   |                   | -                             |

*Legend: 9-10 (Mastered, 96%-100%); 7-8 (Closely Approximating Mastery, 86%-95%); 5-6 (Moving Towards Mastery, 66%-85%), 3-4 (Average Mastery, 35%-65%), 0-2 (Low Mastery, 16%-34%).*

made observable changes (color, gas bubbles, and temperature shifts) directly visible through animated molecular representations—leveraging deaf learners' enhanced visual-spatial processing. The intervention thus provided access to phenomena typically conveyed through auditory-verbal explanations in traditional science instruction.

Competency 2 showed steady improvement with a mean score of 6.43 and a small-to-moderate effect size. While all learners demonstrated positive or maintained performance, gains were less pronounced than in Competency 1. One learner initially in the Low Mastery category (0-2 range) improved to the 3-4 range (Average Mastery), indicating even the lowest-performing learner benefited from the GBL approach. The smaller effect size for Competency 2 likely reflects the abstract conceptual nature of pH and acid-base chemistry, which relies heavily on terminology often lacking standardized sign language equivalents in Filipino Sign Language (FSL).

Teacher reflective journals documented repeated vocabulary negotiation for terms like "neutralization" and "alkaline." Lang and Pagliaro (2007) document that scientific vocabulary gaps in sign languages create significant barriers to deaf students' STEM learning—a phenomenon evident in this competency's more modest gains despite identical visual-spatial affordances.

Competency 3 maintained the highest absolute performance, achieving a mean of 8.00 and reaching the Closely Approximating Mastery category. Post-intervention, two learners (28.57%) achieved the Mastered level (9-10 range) compared to a single learner pre-intervention. The large effect size ( $d = 0.88$ ) is notable given the group's baseline performance, suggesting the intervention avoided ceiling effects and enabled continued conceptual deepening even among initially high performers.

This growth in reaction type classification supports Gardner's (1983) framework: tasks emphasizing visual-spatial pattern recognition align with deaf learners' cognitive strengths, enabling both accessibility and continued growth through enhanced visual representations of molecular rearrangements in synthesis, decomposition, and replacement reactions.

Effect sizes ranged from  $d = 0.39$  to  $d = 1.43$ , with a mean effect size of  $d = 0.90$  (large effect). The overall performance reached a Grand Mean of 20.00 ( $SD = 3.46$ ), placing the group in the Mastery category. This indicates that the GBL intervention produced meaningful learning gains across diverse content types, with the greatest impact on visually observable phenomena (Competency 1).

The universal positive response (100% of learners improved) provides strong descriptive evidence that the GBL approach was broadly accessible within this SPED context, supporting the claim that visual-spatial instruction aligns with deaf learners' cognitive strengths. However, the variation in effect sizes indicates that content type matters: future models must address the specific needs of abstract versus concrete chemical concepts.

### Cross-Case Analysis of Individual Performance Profiles

Table 4 reveals that all seven embedded units demonstrated positive gains, with improvements ranging from +2 to +5 points. However, variation exists in the magnitude of gains, allowing classification into three performance profiles that illuminate differential response patterns to the GBL intervention.

**Table 4.** Individual Learner Performance Profile

| Learner ID | Competency 1 | Competency 2 | Competency 3 | Post test | Pre Test | Gain | Independence Level | Profile         |
|------------|--------------|--------------|--------------|-----------|----------|------|--------------------|-----------------|
| L1         | 6            | 5            | 6            | 17        | 14       | 3    | Moderate           | Moderate Gainer |
| L2         | 7            | 8            | 9            | 24        | 19       | 5    | High               | High Gainer     |
| L3         | 8            | 8            | 9            | 25        | 22       | 3    | High               | Moderate        |

|                                   |      |      |      |                     |                     |                    |             |                 |
|-----------------------------------|------|------|------|---------------------|---------------------|--------------------|-------------|-----------------|
|                                   |      |      |      |                     |                     |                    |             | e Gainer        |
| L4                                | 6    | 7    | 8    | 21                  | 18                  | 3                  | High        | Moderate Gainer |
| L5                                | 4    | 3    | 7    | 14                  | 12                  | 2                  | Low         | Lower Gainer    |
| L6                                | 6    | 7    | 7    | 20                  | 16                  | 4                  | Moderate    | High Gainer     |
| L7                                | 6    | 7    | 8    | 21                  | 19                  | 2                  | High        | Lower Gainer    |
| <b>Overall Mean, SD, and Gain</b> | 6.14 | 6.43 | 7.71 | <b>17.14 (3.14)</b> | <b>20.29 (3.53)</b> | <b>3.14 (0.99)</b> | <b>0.94</b> |                 |

*Note: Individual gains ranged from 2 to 5 points. Mastery categories based on DepEd K-12 rubric: 0-2 (Low Mastery, 16%-34%), 3-4 (Average Mastery, 35%-65%), 5-6 (Moving Towards Mastery, 66%-85%), 7-8 (Closely Approximating Mastery, 86%-95%), 9-10 (Mastered, 96%-100%). Profile categories: High Gainer (gain  $\geq$  4 points), Moderate Gainer (3 points), Lower Gainer ( $<$  3 points).*

Individual performance across the three core competencies further explains these growth patterns. Competency 3 (Describing types of chemical reactions) showed the highest overall mastery with a mean of 7.71, indicating that the visual and interactive nature of the digital simulations was most effective for conceptualizing reaction types. Competency 2 (Identifying common acids, bases, and salts) followed with a mean of 6.43, while Competency 1 (Describing indicators for chemical reactions) had the lowest mean at 6.14. This gradient suggests that while learners struggled more with the abstract identification of chemical indicators, they found greater success in the simulation's ability to categorize and visualize reaction processes.

High Gainers like L2 and L3 achieved "Closely Approximating Mastery" or "Mastered" levels in Competency 3 (scoring 9/10), suggesting that their high independence levels allowed them to fully leverage the simulation's complex modeling. In contrast, L5, the "Lower Gainer," struggled significantly with Competency 2 (scoring 3/10), highlighting that identifying specific chemical substances remains a challenge for learners with low independence and low baseline knowledge, even with GBL intervention.

Learner L2, with high independence level, demonstrated the highest gain (+5 points), improving from 19/30 (63.33%, Moving Towards Mastery) to 24/30 (80.00%, Closely Approximating Mastery). Learner L6, with moderate independence level, gained +4 points (16/30 to 20/30). This pattern suggests that high gains are achievable across different independence levels with appropriate instructional support—L2's self-directed exploration was complemented by teacher availability for clarification, while L6's structured scaffolding enabled similar magnitude gains through guided discovery.

The High Gainer profile challenges deterministic relationships between baseline characteristics and learning outcomes. L2 did not have the highest pre-test (L3: 22/30 was highest) yet achieved the greatest gain, suggesting factors beyond prior knowledge—such as engagement quality, intrinsic motivation, and cognitive flexibility—mediate intervention response.

Three learners demonstrated consistent gains of +3 points. Interestingly, two of these learners (L3, L4) exhibited high independence levels, while L1 demonstrated moderate independence. This consistency suggests that the GBL intervention provided stable benefits across diverse learner profiles within the case context.

The case of L3 is particularly theoretically significant: despite the highest pre-test score (22/30, 73.33%), L3 gained +3 points, reaching 25/30 (83.33%, Closely Approximating Mastery). This demonstrates the intervention avoided ceiling effects—high performers continued to deepen conceptual understanding rather than plateauing. This aligns with Vygotsky's (1978) ZPD framework: appropriately challenging tasks enable growth regardless of current performance level.

Learner L5, with low independence level and the lowest pre-test score (12/30), required substantial one-on-one scaffolding throughout the intervention and gained +2 points. Learner L7, despite high independence level and mid-range pre-test performance (19/30), also showed modest gains of +2 points.

The case of L7 is theoretically puzzling and methodologically instructive. High independence typically predicts strong GBL response **Error! Reference source not found.**, yet L7's modest gain suggests independence alone is insufficient. Teacher field notes indicate L7 "worked independently but seemed disengaged, completed simulations quickly but superficially."

This pattern suggests that independence without engagement or conceptual depth-seeking may limit learning—a finding with implications for the Enhanced Model's differentiated supports.

Across the seven embedded units, gains ranged from +2 to +5 points ( $M = 3.14$ ,  $SD = 0.99$ , range = 3). The relatively low standard deviation ( $SD < 1.0$ ) indicates **\*\*moderate consistency** in intervention response, while the 2.5-fold difference between minimum and maximum gains (ratio = 2.5) reveals meaningful individual variation worth examining. Calculating the coefficient of variation ( $CV = SD/M = 0.99/3.14 = 0.315$ , or 31.5%) confirms moderate variability—lower than would suggest idiosyncratic responses, but higher than would indicate uniform impact.

The observed variation in gain magnitude aligns with Vygotsky's (1978) Zone of Proximal Development (ZPD) theory and Bruner's (1966) scaffolding framework. Learners with high independence levels (L2, L3, L4, L7) could navigate digital simulations with minimal teacher support, enabling self-directed exploration—a key mechanism for deep learning in constructivist pedagogy **Error! Reference source not found.** In contrast, low-independence learners (L5) required extensive scaffolding, limiting time for independent discovery and potentially constraining learning depth.

However, the case of L7 (high independence, low gain) demonstrates that independence is necessary but not sufficient; factors such as engagement quality, prior misconceptions, or motivational orientation also influence outcomes. The finding that baseline knowledge did not predict gain magnitude (highest baseline L3 gained +3; highest gain L2 had mid-range baseline) is particularly theoretically significant.

This null correlation suggests the GBL intervention avoided both ceiling effects (high performers continuing to grow) and floor effects (low performers unable to access content), indicating the digital simulations provided appropriately differentiated entry points across the baseline knowledge spectrum—a hallmark of effective Universal Design for Learning **Error! Reference source not found.**

### **Cross-Case Pattern Analysis**

Cross-case analysis identified common patterns and variations across the seven embedded units. Three key patterns emerged:

**Universal Positive Response:** All seven learners showed improvement, with no cases of negative or negligible gains. This suggests the GBL approach was universally accessible and beneficial within this SPED context.

**Consistency Across Competencies:** Analysis revealed that gains were observed across all three competencies (chemical reaction indicators, acids-bases-salts, and reaction types), indicating comprehensive conceptual development rather than isolated skill improvement.

**Independence-Performance Relationship:** Learners with high independence levels (L2, L3, L4, L7) tended to demonstrate stronger or consistent gains, while learners requiring more support (L1, L5, L6) showed more varied outcomes, suggesting that independence and self-direction may mediate learning outcomes.

### Engagement and Motivation Results

Table 5 presents learner engagement and motivation scores based on a 5-point Likert scale survey administered after the intervention. The survey assessed five dimensions: interest in the activity, perceived ease of use, visual clarity, active participation, and motivation to learn more about chemistry. It also presents teacher observation data on ten behavioral indicators of engagement, assessed using a 4-point frequency scale (1=Never observed, 2=Sometimes observed, 3=Often observed, 4=Always observed) across all 18 intervention sessions. The overall mean engagement rating of 3.73 indicates very high behavioral engagement, suggesting the GBL intervention successfully captured and sustained learners' attention and active participation.

**Table 5.** Observable Learner Behaviors During GBL Sessions (n=7)

| Observable Behavior  | Mean        | SD          | Category               |
|--|-------------|-------------|------------------------|
| 1. Learner attends visually to the computer or game screen           | 3.86        | 0.38        | Always Observed        |
| 2. Learner follows on-screen instructions without repeated prompting | 3.57        | 0.53        | Always Observed        |
| 3. Learner interacts appropriately with the game controls            | 3.43        | 0.53        | Always Observed        |
| 4. Learner completes assigned tasks or levels in the game            | 3.43        | 0.79        | Always Observed        |
| 5. Learner demonstrates understanding through correct responses      | 3.71        | 0.49        | Always Observed        |
| 6. Learner remains engaged for the duration of the activity          | 3.71        | 0.49        | Always Observed        |
| 7. Learner attempts to solve problems presented in the game          | 3.86        | 0.38        | Always Observed        |
| 8. Learner responds positively to visual feedback                    | 3.86        | 0.38        | Always Observed        |
| 9. Learner communicates with peers/teacher using sign language       | 2.86        | 0.38        | Often Observed         |
| 10. Learner shows improvement as the activity progresses             | 3.71        | 0.49        | Always Observed        |
| Overall  | <b>3.60</b> | <b>0.48</b> | <b>Always Observed</b> |

*Legend: 3.25-4.00 = Always Observed, 2.50-3.24 = Often Observed, 1.75-2.49 = Sometimes Observed, 1.00-1.74 = Never Observed*

Learners consistently maintained focus on simulation displays, with minimal off-task looking or distraction. This sustained visual engagement is particularly significant for deaf learners, whose primary sensory channel for learning is visual. Learners demonstrated observable reactions (smiling, nodding, signing excitement) when simulations provided correct-answer confirmation or revealed chemical processes visually. This immediate feedback loop is a core GBL principle and appeared to reinforce continued engagement.

Learners actively manipulated simulation variables, tested hypotheses, and tried alternative approaches when initial attempts failed—demonstrating the "pleasantly frustrating" challenge level that optimal learning environments provide. This contrasts sharply with teacher reports of passive behavior during traditional textbook-based chemistry lessons.

The very high engagement levels observed ( $M = 3.73$ ) contrast markedly with research documenting lower engagement among deaf students in traditional science instruction. Lang et al. (2006) reported mean engagement ratings of 2.8/4.0 for lecture-based chemistry instruction in SPED settings, while Pagliaro (2010) found motivation levels of 2.5/4.0 for textbook-based science learning among deaf students. The 26-49% higher engagement in this GBL case likely reflects the visual-spatial alignment between simulation-based instruction and deaf learners' cognitive strengths. **Error! Reference source not found.**

Furthermore, while the overall engagement ratings were consistently high, qualitative observation notes revealed meaningful variations in how learners initially interacted with the simulation before achieving sustained engagement. In one observed case during the early sessions, a learner initially struggled to follow the sequence of steps required to complete a reaction task. The learner repeatedly selected incorrect reactant combinations and hesitated when navigating the interface, requiring minimal prompting from the teacher.

Observation notes indicated that the learner appeared visually focused but uncertain, pausing frequently and looking at peers before attempting an action. However, as the sessions progressed, the same learner demonstrated noticeable improvement in both confidence and task completion. By the third session, the learner was able to independently manipulate variables and complete levels without assistance. A recorded observation note stated: "Learner initially hesitated and relied on peer cues, but later began initiating actions independently and showed visible excitement (smiling, nodding) after correct responses." This progression highlights how the game-based digital simulation provided a low-risk environment for trial-and-error learning, allowing the learner to gradually build competence.

Such instances support the principle that engagement in game-based environments is not merely immediate but can develop over time as learners become familiar with the system and gain confidence in their abilities. This finding reinforces the idea that GBL environments foster persistence and resilience, particularly among deaf learners who benefit from visually guided, feedback-rich instructional contexts. The high engagement persisted across all six weeks (no significant decline over time noted in teacher logs), suggesting the novelty effect often associated with educational technology did not account for engagement patterns. Rather, the sustained engagement suggests genuine alignment between instructional modality and learner characteristics—consistent with Self-Determination Theory's prediction that autonomy-supportive, competence-building environments foster intrinsic motivation.

### **Learner Perceptions of GBL (Self-Report Survey)**

Table 6 presents learner perceptions of the GBL experience based on a 4-point Likert scale survey. The survey assessed ten dimensions related to understanding, usability, motivation, and satisfaction. The table also presents learner self-report data on ten perception statements, assessed using a 4-point Likert scale (1=Strongly Disagree, 2=Disagree, 3=Agree, 4=Strongly Agree). The overall mean perception rating of 3.82 indicates very positive learner perceptions of the GBL intervention's effectiveness, usability, and motivational value.

*"Simulations helped me understand chemistry"* ( $M = 3.86$ ): This direct self-assessment of learning effectiveness validates the quantitative gains shown in Tables 1-2. Learners perceived the simulations as genuinely educative, not merely entertaining. Likewise, *"I want more simulations like this in future lessons"* ( $M = 3.86$ ):

**Table 6.** Learner Perceptions of Game-Based Learning

| Perception Statement   | Mean        | SD          | Category              |
|--|-------------|-------------|-----------------------|
| <b>1. The digital simulations helped me understand chemical reactions</b>          | 3.71        | 0.49        | Strongly Agree        |
| <b>2. The instructions and visuals were clear and easy to follow</b>               | 3.71        | 0.49        | Strongly Agree        |
| <b>3. I could identify indicators of chemical reactions through the simulation</b> | 3.71        | 0.49        | Strongly Agree        |
| <b>4. The simulation allowed me to explore reactions actively and safely</b>       | 3.71        | 0.49        | Strongly Agree        |
| <b>5. I was motivated to participate because of the simulation</b>                 | 3.71        | 0.49        | Strongly Agree        |
| <b>6. The time given to complete activities was enough</b>                         | 3.86        | 0.38        | Strongly Agree        |
| <b>7. I enjoyed learning chemical reactions through digital simulations</b>        | 3.86        | 0.38        | Strongly Agree        |
| <b>8. The simulation used language/symbols/visuals I could understand</b>          | 3.57        | 0.53        | Strongly Agree        |
| <b>9. The simulation encouraged me to explore more science topics</b>              | 3.86        | 0.38        | Strongly Agree        |
| <b>10. I would like to use similar simulations in future lessons</b>               | 3.86        | 0.38        | Strongly Agree        |
| Overall  | <b>3.74</b> | <b>0.45</b> | <b>Strongly Agree</b> |

Legend: 3.25-4.00 = Strongly Agree, 2.50-3.24. = Agree, 1.75-2.49 = Disagree, 1.00-1.74 = Strongly Disagree.

High desire for continued GBL use suggests positive affective response and perceived value—critical for sustained engagement in future STEM learning. Lastly, “*I was motivated to participate in the activities*” (M = 3.86): Self-reported intrinsic motivation aligns with behavioral observations (Table 4) and supports Self-Determination Theory's prediction that autonomy-supportive learning environments enhance motivation.

The convergence of teacher observations (Table 4: M = 3.73, "Very High") and learner self-reports (Table 5: M = 3.82, "Very Positive") provides triangulated evidence of high engagement and motivation during the GBL intervention. This methodological triangulation strengthens confidence in findings by demonstrating consistency across data sources (observer vs. participant perspectives) and measurement approaches (behavioral frequency ratings vs. attitudinal agreement scales).

Moreover, the slight difference in magnitude (learner perceptions 0.09 points higher than teacher observations) may reflect social desirability bias in self-reports or genuine differences in internal experience versus observable behavior. Regardless, both measures exceeded the threshold for "high/positive" ( $\geq 3.5$ ), providing robust evidence of intervention acceptability.

### **Patterns emerge from within-case synthesis and cross-case analysis of the seven embedded units?**

This research question integrates findings from RQ1 through RQ5 to identify overarching patterns characterizing the bounded case of GBL implementation at Naga SPED Center, as well as variations among the seven embedded units (individual deaf learners). The analysis follows Yin's (2018) embedded case study framework, examining both the holistic case level and the embedded unit

level to develop comprehensive understanding of how the GBL intervention functioned in this specialized SPED context.

### **Within-Case Synthesis: Characterizing the GBL Implementation Case**

Within-case synthesis examines the bounded case as a unified whole, identifying patterns that characterize the overall GBL implementation context at Naga SPED Center. Four major patterns emerged:

#### **Pattern 1: Universal Accessibility and Positive Response**

All seven embedded units (100%) demonstrated positive learning gains following the GBL intervention, with improvements ranging from +2 to +5 points ( $M = 3.14$ ,  $SD = 0.99$ ). No learners experienced negative or stagnant performance, despite considerable variation in:

- Baseline knowledge (pre-test range: 12-22 out of 30)
- Degree of hearing loss (moderate to profound)
- Independence levels (low, moderate, high)
- Communication modes (American Sign Language vs. Filipino Sign Language)

This universal positive response pattern suggests that the GBL approach, as implemented in this bounded case, was fundamentally accessible and beneficial across diverse learner profiles within the SPED context. The visual-spatial nature of digital simulations effectively compensated for auditory-verbal barriers inherent in traditional chemistry instruction.

#### **Pattern 2: Competency-Specific Improvement Trajectories**

Analysis across all embedded units revealed differential improvement patterns by competency:

**Competency 1** (Chemical Reaction Indicators) showed the **largest mean gain** (+1.57 points) and the only instance of **mastery category advancement** (Average Mastery → Moving Towards Mastery). This suggests that visual demonstrations of observable chemical changes (color, precipitate, gas, temperature) aligned particularly well with deaf learners' visual-spatial cognitive strengths.

**Competency 2** (Acids, Bases, Salts) demonstrated **moderate gains** (+0.71 points) but remained within the same mastery category. The abstract nature of pH concepts and reliance on terminology (lacking standardized sign language equivalents) may have limited gains in this competency.

**Competency 3** (Types of Chemical Reactions) maintained **consistently high performance** both pre- and post-intervention (pre-test: 7.43; post-test: 8.29), with progression to Closely Approximating Mastery. The pattern-recognition nature of this competency (identifying reaction types by structural formulas) appeared well-suited to visual learning approaches.

These competency-specific trajectories indicate that the GBL intervention's effectiveness varied by content type, with greatest impact on visually observable phenomena and least impact on abstract conceptual understanding requiring specialized vocabulary.

#### **Pattern 3: High Engagement and Positive Affect**

Behavioral observations (RQ4) revealed consistently high engagement levels ( $M = 3.73$  out of 4.00, interpreted as "High"), with particularly strong performance in:

- Visual attention to screen ( $M = 3.86$ , "Very High")
- Positive response to visual feedback ( $M = 3.86$ , "Very High")
- Problem-solving attempts ( $M = 3.86$ , "Very High")

Learner perceptions (self-report) showed even stronger positive affect (M = 3.82 out of 4.00, "Very Positive"), with highest ratings for:

- Understanding through simulations (M = 3.86)
- Desire for similar simulations in future (M = 3.86)
- Motivation to participate (M = 3.86)

The convergence of teacher observations and learner self-reports provides robust evidence that the GBL intervention not only produced cognitive gains but also fostered affective outcomes conducive to sustained science learning. This dual impact—cognitive and affective—characterizes the case as a holistically successful intervention.

#### **Pattern 4: Implementation Feasibility Despite Contextual Challenges**

Despite documented challenges (RQ5)—technical connectivity issues, sign language terminology gaps, differentiated pacing needs—the intervention was successfully implemented within existing SPED infrastructure. The teacher's adaptation strategies (one-on-one scaffolding for L5, ad-hoc sign language negotiation, flexible pacing) enabled sustained implementation over the six-week period.

This pattern suggests that GBL interventions, while presenting implementation challenges in SPED contexts, are pragmatically viable when teachers possess both content knowledge and responsiveness to learner needs. The case demonstrates that technological and linguistic barriers, while real, are surmountable through instructional adaptation.

### **6.2 Cross-Case Analysis: Variations Among Embedded Units**

While within-case synthesis reveals overarching patterns characterizing the case as a whole, cross-case analysis examines how the seven embedded units responded differently to the intervention. This analysis identifies both consistent patterns and instructive variations.

#### **Consistent Cross-Case Pattern: Directionality of Change**

Despite variations in magnitude, all seven embedded units demonstrated positive directionality (100% improvement rate). This consistency across embedded units—even including L5 (lowest independence, lowest baseline) and L7 (high baseline, modest gain)—provides strong evidence that the GBL approach was fundamentally sound for this population and context.

#### **Variation 1: Magnitude of Gains (High, Moderate, Lower Gainers)**

Embedded units clustered into three gain profiles:

**Table 7.** Gain Profile Distribution

| <b>Profile</b>   | <b>Criteria</b> | <b>Embedded Units</b> | <b>% of Sample</b> | <b>Characteristics</b>  |
|------------------|-----------------|-----------------------|--------------------|---|
| High Gainers     | ≥ 4 points      | L2, L6                | 28.57              | High/Moderate independence; responsive to visual-spatial instruction; active simulation exploration |
| Moderate Gainers | 3 points        | L1, L3, L4            | 42.86              | Mixed independence levels; consistent baseline improvement; steady engagement                       |
| Lower Gainers    | < 3 points      | L5, L7                | 28.57              | L5: Low independence, required scaffolding; L7: High independence but modest gain                   |

Table 7 presents the distribution of learners across three gain profile categories based on magnitude of pre-to-post improvement. The distribution reveals that 71.43% of learners achieved moderate-to-high gains (≥3 points), while 28.57% demonstrated lower gains (<3 points). This pattern provides

insight into the intervention's differential impact and identifies learner characteristics associated with varied response patterns.

#### High Gainers (n=2, 28.57%): Exemplary Response

The two High Gainers (L2: +5 points, L6: +4 points) represent learners who maximized the GBL affordances. Detailed case analysis (see individual case studies) reveals these learners shared:

- *Strong task persistence and problem-solving orientation*
- *Positive affective response to technology-enhanced learning*
- *Ability to transfer simulation learning to test performance*
- *Active exploration beyond minimum task requirements*

Notably, High Gainers did NOT share uniform profiles in all characteristics—L2 had high independence while L6 had moderate independence, and their baseline knowledge differed (L2: 19/30, L6: 16/30). This heterogeneity suggests multiple pathways to high gains exist, rather than a single "ideal learner" profile.

#### Moderate Gainers (n=3, 42.86%): Consistent Response

The three Moderate Gainers (L1, L3, L4: all +3 points) represent the modal response pattern. This consistency is theoretically significant: despite varying baseline knowledge (L3: 22/30 was highest; L1: 14/30 was lower), varying communication modes (L1, L4: ASL; L3: FSL), and varying family backgrounds (L4 from Deaf family; L1, L3 from hearing families), all achieved identical +3-point gains.

This consistency suggests the GBL intervention provided a "stable benefit floor"—a minimum level of effectiveness accessible to most learners regardless of heterogeneity in background characteristics. This finding aligns with Universal Design for Learning (UDL) principles: well-designed inclusive instruction benefits diverse learners without requiring individualized adaptations for every difference.

#### Lower Gainers (n=2, 28.57%): Barriers to Optimal Response

The two Lower Gainers (L5, L7: both +2 points) represent learners who benefited from the intervention but faced barriers limiting optimal response. Critically, these two learners faced DIFFERENT barriers:

*L5 (low independence, lowest baseline) faced:*

- *Cognitive load challenges requiring extensive scaffolding*
- *Reading comprehension barriers limiting test performance*
- *Limited prior technology exposure requiring extended orientation*

*L7 (high independence, mid-range baseline) faced:*

- *Possible disengagement or superficial engagement patterns*
- *Reluctance to seek help when conceptually stuck*
- *Late-onset deafness potentially affecting visual-spatial development differently than congenital deafness*

The fact that Lower Gainers had different barrier profiles suggests the Enhanced Model (RQ7) must provide multiple differentiated supports rather than a single "remediation" approach.

The gain profile distribution suggests that GBL implementation in similar SPED contexts should expect:

- Approximately 25-30% of learners will show exceptional response ( $\geq 4$  points gain)
- Approximately 40-45% will show consistent moderate response (+3 points gain)
- Approximately 25-30% will show positive but modest response ( $< 3$  points gain)

This distribution informs resource allocation decisions: most learners will benefit from standard GBL implementation, but approximately one-third will require additional differentiated supports to achieve optimal outcomes. The Enhanced Model (RQ7) must address both universal design principles and differentiated support strategies to serve this full range of response patterns.

### **Chapter 3**

#### **Summary of Findings, Conclusion, and Recommendations**

This chapter entailed the study's overview, research results, and conclusions. This part of the chapter also comprises recommendations based on the findings.

#### **Summary of Findings**

This study investigated the effectiveness of game-based learning (GBL) through digital simulations in teaching chemical reactions to Grade 10 deaf learners at Naga Special Education Center using an embedded single-case study design.

The implementation of Game-Based Learning within the Grade 10 Science classroom demonstrated that the intervention functioned effectively as a visually rich, interactive, and learner-centered approach. It actively engaged deaf learners in exploring chemical reaction concepts through digital simulations, supporting meaningful participation in the learning process.

Prior to the intervention, the deaf learners exhibited limited conceptual understanding of chemical reaction concepts, particularly in identifying indicators of chemical reactions, recognizing acids, bases, and salts, and describing different types of chemical reactions. This indicates a need for instructional strategies that are more aligned with their learning needs and cognitive processing.

After the implementation of the intervention, a marked improvement in conceptual understanding was observed, as reflected in the increased post-test scores across all embedded units. This suggests that the use of digital simulations effectively supported the learning of abstract science concepts.

High levels of engagement and motivation were consistently observed during the learning sessions. Learners demonstrated active participation, sustained attention, and positive responses during simulation-based activities, particularly when visual representations of chemical processes were presented.

Despite the positive outcomes, several implementation challenges were identified, including technical difficulties during simulation use, differences in learner readiness, and the need for additional teacher support in integrating digital tools into instruction.

Analysis across cases revealed consistent patterns of improvement among all seven embedded units, particularly in conceptual understanding and engagement, although variations in learning gains were evident depending on the learners' initial proficiency levels.

The overall findings informed the development of an Enhanced Game-Based Instructional Model for Deaf Learners, designed to improve accessibility and deepen understanding of abstract scientific concepts through structured, visually oriented, and interactive learning experiences.

## Conclusion

The study concludes that Game-Based Learning through digital simulations is an effective instructional approach for deaf learners in understanding abstract science concepts such as chemical reactions. The intervention improved conceptual understanding, increased learner engagement, and enhanced motivation by leveraging the visual-spatial strengths of deaf learners. Despite implementation challenges, the overall results demonstrate that technology-enhanced, learner-centered instruction significantly supports inclusive science education when properly designed and implemented.

## Recommendation

The study presents several recommendations based on its findings and conclusions. Science teachers in inclusive education are encouraged to undergo specialized training, seminars, and workshops focused on the integration of digital simulations and game-based learning strategies to enhance their capacity in designing instruction that reduces reliance on linguistic translation and maximizes the use of visual-spatial learning tools. Schools are likewise encouraged to strengthen resource provision by ensuring the availability of digital devices such as tablets, interactive software, and stable technological infrastructure to effectively support diverse learner needs in inclusive classrooms.

For students, particularly deaf learners, the use of visual and interactive learning tools such as simulations is recommended to strengthen conceptual understanding and engagement in science learning. For future researchers, it is recommended that further studies be conducted to explore the long-term retention effects of game-based learning and can be done it embedded multiple case study, its application in other science domains, and its scalability across different inclusive education settings.

Curriculum planners are further encouraged to integrate game-based learning approaches into the science curriculum to ensure that instructional materials are accessible and responsive to learners with hearing impairments. In addition, support from inclusive education specialists and instructional technology experts is recommended to ensure effective implementation, teacher capacity-building, and the sustainable integration of digital learning tools. Finally, further studies are recommended to explore long-term learning retention, domain-specific scientific reasoning, and independent learning outcomes of deaf learners exposed to game-based learning and digital simulation-based instruction.

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