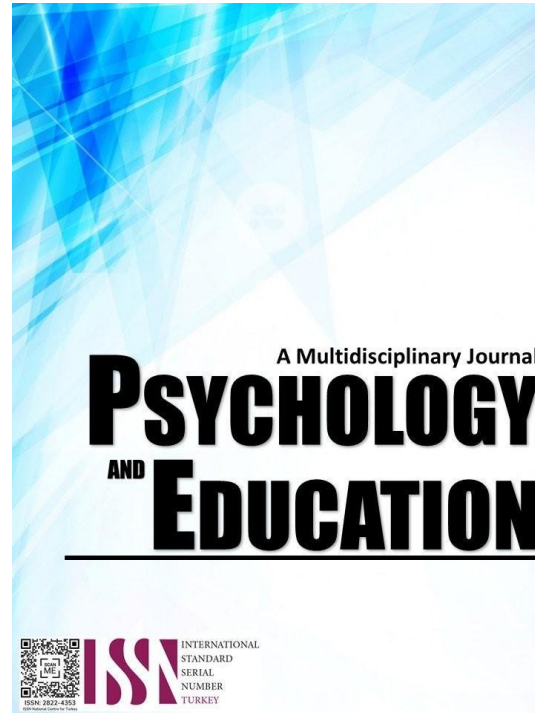


PHET VIRTUAL SIMULATIONS WITH TRADITIONAL LEARNING TOOLS IN SCIENCE TEACHING: VOICES FROM CHEMISTRY TEACHERS



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PhET Virtual Simulations with Traditional Learning Tools in Science Teaching: Voices from Chemistry Teachers

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Abstract

This study explored chemistry teachers' lived experiences in integrating PhET virtual simulations with traditional instructional tools to enhance students' critical thinking skills in STEM education. Guided by a qualitative phenomenological research design, the study examined how teachers implemented simulation-based instruction within authentic classroom contexts and how such integration influenced instructional practices and student engagement. The participants consisted of seven STEM teachers from the Division of Naga City who had experience teaching General Chemistry and using PhET simulations for at least six months. Purposive sampling was employed to ensure that participants possessed relevant instructional experiences related to the phenomenon under investigation. Data were collected through semi-structured interviews, classroom observations, and document analysis of lesson plans and instructional materials. The gathered data were analyzed using thematic analysis following Braun and Clarke's (2019) framework, with triangulation employed to strengthen the credibility and trustworthiness of the findings. The analysis generated five major themes: (1) PhET simulations foster analytical and critical thinking skills; (2) understanding is enhanced through the integration of virtual and traditional instructional tools; (3) virtual and traditional methods are complementary instructional approaches; (4) implementation is constrained by technical and resource limitations; and (5) combined instructional methods improve student engagement and learning outcomes. Teachers reported that simulations enabled students to predict outcomes, manipulate variables, justify findings, and engage in inquiry-based reasoning. Classroom observations further revealed increased student participation, collaborative discussions, and deeper conceptual understanding when simulations were integrated with guided questioning, printed materials, and hands-on activities. Despite challenges involving limited devices, unstable internet connectivity, and time constraints, teachers demonstrated adaptability by employing collaborative learning strategies and contextualized instructional adjustments. The findings emphasized that effective technology integration requires intentional pedagogical planning, contextual responsiveness, and balanced use of digital and traditional teaching approaches to promote meaningful learning and higher-order thinking skills in chemistry education.

Keywords: *higher-order thinking skills, STEM education, PhET simulations, technology integration, teachers' experiences*

Introduction

Science education plays a crucial role in preparing learners for the demands of the twenty-first century, particularly in the fields of science, technology, engineering, and mathematics (STEM). As technological advancement continues to reshape modern society, educational institutions are challenged to adopt instructional strategies that cultivate scientific literacy, critical thinking, and problem-solving skills among students. Chemistry, in particular, remains one of the most conceptually demanding branches of science because many of its principles involve microscopic and abstract processes that are difficult to visualize through conventional classroom instruction alone. Traditional teaching approaches that rely heavily on textbooks, lectures, and printed materials may limit students' engagement and conceptual understanding, thereby affecting their motivation and academic performance. Consequently, educators increasingly recognize the importance of integrating technology-based instructional tools to enhance learning experiences and improve students' comprehension of complex scientific concepts.

The integration of digital technologies in science instruction has resulted in the emergence of interactive learning platforms designed to support active and experiential learning. Among these innovations are the PhET Interactive Simulations developed by the University of Colorado Boulder, which provide learners with opportunities to manipulate variables, observe scientific phenomena, and engage in inquiry-based exploration in virtual environments. These simulations have gained recognition as effective instructional tools across various educational levels because they enable students to visualize otherwise abstract scientific processes and participate actively in learning activities. Previous studies have indicated that PhET simulations are particularly effective in secondary science education and remain valuable in online and blended learning environments (Pranata, 2024). Their accessibility in both online and offline formats further contributes to their applicability in diverse educational contexts.

International literature has consistently demonstrated the instructional effectiveness of interactive simulations in improving students' conceptual understanding and higher-order thinking skills. Studies revealed that students exposed to PhET-based instruction exhibit stronger reasoning, analytical, and problem-solving abilities compared with learners who experience purely traditional teaching methods (Diab et al., 2024). Similarly, Hasyim et al. (2020) found that structured learning activities incorporating prediction, analysis, and evidence-based reasoning significantly enhanced students' critical thinking skills when integrated with PhET simulations. Other investigations also emphasized that combining simulations with inquiry-based and problem-based learning approaches contributes to

substantial gains in analytical and problem-solving competencies in challenging STEM disciplines (Al-Biruni, 2022; Pertiwi et al., 2024; Syawaludin et al., 2019). These findings suggest that technology-enhanced instruction can foster deeper cognitive engagement and meaningful learning experiences among students.

Recent studies further highlighted that the effectiveness of simulations depends largely on intentional pedagogical integration rather than passive observation of digital outputs. Banda and Nzabahimana (2021) and Keller et al. (2018) reported that learners demonstrate improved conceptual understanding when simulations are embedded within guided instructional activities. Likewise, Hwang and Chen (2017) and Onyekuru (2023) emphasized that simulations become more meaningful when students are encouraged to interpret results, justify conclusions, and apply evidence-based reasoning. While these studies strongly support the educational value of PhET simulations, most existing research predominantly focuses on student outcomes and academic achievement. Limited attention has been devoted to understanding the lived experiences and instructional perspectives of teachers who implement these technologies in actual classroom settings. As teachers remain central agents in instructional innovation, examining their experiences is essential in understanding how technology integration influences classroom practices and learning processes.

In the Philippine educational context, the integration of technology into classroom instruction has been strongly advocated through national educational reforms and policy frameworks. The Department of Education, through DepEd Order No. 42, s. 2017 or the Philippine Professional Standards for Teachers emphasized the importance of integrating information and communication technology (ICT) in teaching and learning processes. These reforms align with the broader objective of promoting twenty-first-century competencies, including critical thinking, collaboration, creativity, and digital literacy. Despite these initiatives, many Philippine schools continue to encounter challenges related to technological infrastructure, resource availability, and teachers' preparedness for digital integration, particularly in science and STEM classrooms. These realities influence the extent to which teachers can effectively balance traditional instructional methods with technology-supported pedagogies.

Local studies on the use of PhET simulations in Philippine classrooms remain relatively limited but provide promising evidence regarding their educational potential. Potane and Bayeta (2018), for instance, investigated the implementation of PhET simulations in pilot schools in Cagayan de Oro City and found that students exposed to virtual learning environments demonstrated satisfactory academic performance and significant improvements between pretest and posttest assessments. The study further indicated that students perceived virtual learning positively and found the learning experience engaging and motivating. Such findings suggest that simulation-based instruction may contribute not only to cognitive development but also to increased student interest and participation in science learning. However, despite the growing body of evidence supporting the effectiveness of PhET simulations, there remains a scarcity of qualitative investigations that explore teachers' firsthand experiences in integrating these tools within chemistry instruction in Philippine secondary schools.

Another critical issue identified in the literature concerns the contextual factors influencing successful technology integration in classrooms. Studies revealed that access to technological resources, internet connectivity, and availability of digital devices significantly affect the implementation of simulation-based instruction (Liu et al., 2020). In many developing educational settings, teachers often face challenges associated with limited infrastructure, insufficient technical support, and varying levels of digital competence among learners. These contextual realities highlight the need to examine how teachers navigate such challenges while integrating PhET simulations alongside traditional instructional materials. Understanding these experiences is particularly important in chemistry education, where instructional decisions greatly influence students' ability to comprehend complex and abstract scientific concepts.

Given these gaps in the literature, the present study explored chemistry teachers' perspectives on the integration of PhET virtual simulations and traditional instructional materials in enhancing students' higher-order thinking skills. Using a phenomenological research approach, the study sought to capture the lived experiences of teachers and examine how instructional integration occurs in actual classroom practice. Specifically, the study aimed to provide insights into the opportunities, challenges, and pedagogical implications associated with combining traditional and technology-based instruction in chemistry education. The findings of this study may contribute to the development of evidence-based teaching practices, support curriculum innovation, and encourage STEM educators to adopt more interactive and learner-centered instructional approaches. Furthermore, the study may provide valuable implications for educational leaders, curriculum developers, and policymakers in strengthening technology integration initiatives that promote meaningful and effective science learning experiences.

Research Questions

The primary purpose of this study was to explore STEM teachers' experiences with the integration of PhET virtual simulations and traditional learning tools in supporting the development of students' critical thinking skills. Specifically, the study sought to answer the following questions:

1. What are the lived experiences of chemistry teachers in implementing PhET virtual simulations alongside traditional teaching methods to enhance students' critical thinking skills?
2. What is the essence of the chemistry teachers' experiences in integrating PhET virtual simulations with traditional teaching?
3. What instructional guide can be developed to enhance the integration of PhET virtual simulations with traditional teaching?

methods?

Methodology

Research Design

This study employed a qualitative research methodology to explore chemistry teachers' perspectives on the integration of PhET virtual simulations and traditional instructional tools in enhancing STEM students' critical thinking skills. Specifically, the study utilized a phenomenological research design to investigate the lived experiences, perceptions, and instructional practices of teachers within their natural educational settings. Phenomenology is appropriate for studies that seek to understand the essence and meaning of participants' experiences regarding a particular phenomenon. Through this approach, the study aimed to capture how teachers perceived the instructional integration of digital simulations and traditional teaching methods, including the opportunities, challenges, and pedagogical implications associated with such practices. The phenomenological design also enabled the researcher to gather rich, in-depth descriptions that reflected participants' subjective experiences and interpretations of classroom realities.

Participants

The participants of the study consisted of STEM Science teachers from the Division of Naga City who had experience teaching General Chemistry and had actively utilized PhET virtual simulations alongside traditional instructional materials for at least six months. The inclusion criteria ensured that participants possessed sufficient firsthand experience related to the phenomenon under investigation. Using purposive sampling, seven qualified teachers were selected from secondary schools within the division. Only teachers who had implemented PhET simulations in their chemistry instruction were included in the study to ensure the relevance and richness of the gathered data. The selection process also considered variation in teaching experience by including both novice and experienced teachers to capture diverse perspectives and instructional practices. Such variation allowed the study to explore multiple interpretations and meanings associated with integrating simulation-based and traditional teaching approaches in fostering students' critical thinking skills. Consistent with phenomenological inquiry, the sample size was deemed adequate to obtain detailed and meaningful descriptions of participants' lived experiences.

Instrument

The study utilized semi-structured interviews as the primary data collection instrument. The interview guide consisted of open-ended and close-ended questions designed to elicit comprehensive responses regarding teachers' experiences, perceptions, and instructional strategies related to the integration of PhET simulations and traditional teaching tools. The semi-structured format allowed flexibility for probing and follow-up questions, enabling the researcher to gather deeper insights into participants' lived experiences. The interview protocol was organized according to specific domains of inquiry, with each domain containing three to four questions, including concluding questions, for a total of 21 interview items. Most questions were open-ended to encourage detailed narratives and reflective responses from the participants.

In addition to interviews, document analysis was conducted using lesson plans and related instructional materials to examine how teachers integrated PhET simulations with traditional teaching approaches in classroom instruction. The inclusion of document analysis strengthened the study by providing supporting evidence regarding instructional planning and pedagogical implementation. These research instruments facilitated the collection of rich qualitative data necessary for identifying recurring patterns, themes, and meanings associated with the phenomenon under study.

Procedure

The data collection process was conducted systematically in three phases: pre-data gathering, actual data gathering, and post-data gathering. Prior to data collection, the researcher secured the necessary approvals and permissions by preparing and submitting transmittal letters to the Dean of Education, the School Division Superintendent, and the respective school principals. Upon approval, a Notice to Proceed was issued. The researcher then identified qualified participants through purposive sampling based on the established inclusion criteria. After presenting the division endorsement to school administrators, prospective participants were informed about the objectives and procedures of the study and were provided with informed consent forms. Classroom observations were subsequently scheduled according to participants' availability to document actual instructional integration practices involving PhET simulations and traditional teaching tools.

During the actual data gathering phase, semi-structured interviews were conducted following the classroom observations. The interviews focused on participants' experiences in integrating PhET simulations with conventional instructional materials to enhance students' critical thinking skills. Simultaneously, lesson plans and related instructional documents were reviewed to support document analysis and examine the alignment between instructional planning and classroom implementation. This process enabled the researcher to validate and contextualize participants' responses during the interviews. All interviews were audio-recorded with participants' consent and were later transcribed verbatim to ensure accuracy and completeness of the data. Each participant participated in approximately one classroom observation session lasting 45 to 60 minutes and one interview session lasting 15 to 20 minutes. The total participation time did not exceed two hours to minimize disruption to instructional responsibilities.

Following data collection, all interview transcripts, observation notes, and instructional documents were organized, coded, and securely stored in both physical and password-protected digital formats to maintain confidentiality and data security. Member checking was conducted by allowing participants to review their interview transcripts for accuracy and consistency. The collected data were then prepared for thematic analysis through coding, categorization, and triangulation of multiple data sources, including interviews, classroom observations, and instructional documents. This triangulation process enhanced the credibility and trustworthiness of the findings. A narrative report was subsequently developed using synthesized themes, supported by excerpts and direct quotations from participants. The findings were aligned with the research questions and related literature to ensure analytical rigor and interpretive depth.

Data Analysis

The study employed thematic analysis to systematically analyze and interpret the qualitative data gathered from interviews, classroom observations, and document analysis. Thematic analysis was appropriate because it enabled the researcher to identify, organize, and interpret recurring patterns of meaning across participants' narratives and experiences. Following the framework of Braun and Clarke (2019), the analysis began with data familiarization through repeated reading of interview transcripts, observation notes, and instructional documents. During this stage, significant statements and meaning-bearing units relevant to the phenomenon were identified and documented.

The second stage involved generating initial codes from the collected data. Codes representing similar ideas and experiences were grouped into broader categories and subsequently refined into themes. The coding process focused on concepts related to instructional integration, critical thinking development, student engagement, pedagogical strategies, implementation challenges, and perceptions of instructional effectiveness. Emerging themes were continuously reviewed and refined to ensure coherence, relevance, and alignment with the research objectives.

The third stage involved triangulation and interpretive analysis. Data obtained from interviews, classroom observations, and lesson plan documents were compared to establish consistency and strengthen the credibility of the findings. The researcher interpreted the themes within the broader conceptual and theoretical framework of technology integration and constructivist learning, ensuring that the findings accurately reflected participants' lived experiences. Finally, conclusions were formulated regarding teachers' perspectives on the role of PhET simulations and traditional instructional tools in enhancing students' critical thinking skills. The findings were presented using thematic narratives supported by direct participant quotations and were used as the basis for recommendations for instructional practice and future research.

Ethical Considerations

The study was conducted in accordance with the ethical principles governing educational research and complied with the provisions of the Data Privacy Act of 2012 to ensure the confidentiality, privacy, and protection of participants' personal information. Ethical approval was obtained from the University of the Visayas Research and Ethics Committee prior to the commencement of data collection (Reference No. 2025-0307 dated July 26, 2025). Permission was likewise secured from the Schools Division Office and participating school administrators.

Participants were fully informed regarding the purpose, procedures, potential risks, and benefits of the study before participation. Informed consent was obtained from all participants, and voluntary participation was strictly observed throughout the research process. Participants were informed of their right to withdraw from the study at any stage without penalty or consequence. To uphold confidentiality and anonymity, participant identities were replaced with codes in all transcripts, records, and reports. All research data were securely stored in encrypted digital files and protected physical folders accessible only to the researcher.

The principles of beneficence, respect for persons, and justice guided the conduct of the study. Potential risks were minimized, and efforts were made to ensure that participation did not interfere with teachers' professional responsibilities. No external funding or conflicts of interest were associated with the study. Participants were also provided with access to the summary of findings to promote transparency and ethical accountability. In compliance with institutional ethical guidelines, all raw data, including consent forms, transcripts, and observation notes, will be securely stored for the prescribed retention period before being permanently destroyed through appropriate disposal procedures such as shredding physical documents and deleting encrypted digital files.

Results and Discussion

As the study was conducted, the investigator analyzed the data, presented the results, and discussed the findings based on the responses of seven STEM teachers who were qualified with their corresponding pseudonyms. The thematic analysis was used to analyze the data based on the steps that were modified by Braun and Clarke (2019). The aim of the analysis was to detect general trends in the experiences, perceptions, and difficulties of teachers in employing PhET virtual simulations along with conventional learning resources in developing critical thinking skills in students during classroom discussions.

Table 1. Respondents Profile

Respondent	Position	Years of Teaching	Grade Level	Subject Area	Experience Using PhET
R1	Teacher I	1	11 & 12	Science (Chemistry)	6 months
R2	Teacher II	19	11	Science (Chemistry, Biology, Physical Science)	5 years
R3	Teacher II	5	12	Science (Chemistry, Physical Science)	2 years
R4	Teacher II	8	11 & 12	Science (Biology, Chemistry)	5 years
R5	Teacher II	3	11 & 12	Science (Physical Science, Chemistry)	1 year
R6	Teacher I	1	11 & 12	Science (Earth & Life Science, Chemistry)	6 months
R7	Teacher II	10	12	Science (Physics, Chemistry)	3 years

The data in Table 1 was a summary of the background of the respondents. This gave the results a background and revealed a difference in teaching experience, grade level, and subject area. The respondents comprised both novice and experienced teachers, which enhanced the credibility of the findings since it covered a wide range of data. Furthermore, the data below were the research questions with the corresponding utterances of the respondents and themes. The theme was not a result of single utterances, but it occurred when there were repeated descriptions among the participants. The patterns in the way teachers described their experiences in classrooms were noticed as similar patterns were observed through the repeated reading of the transcripts. They constantly outlined changes in the behavior of students with the introduction of simulations. Instead of having to memorize definitions, students started to predict results, ask themselves questions about the results that they did not expect to get, and give reasons why they think they did so. These recurring accounts constituted initial codes like prediction, justifying results, questioning results, manipulating variables, and further reasoning. When these codes were combined in one way, they indicated a wider direction of critical thinking that resulted in the formation of the theme on critical thinking. The development of the theme was thus based on the real experience in the classroom as opposed to forced interpretation. The convergence in meaning existed among the observed results of the teachers and is very crucial in the phenomenological analysis as outlined by Creswell and Poth (2018).

Theme 1: PhET Simulations help in fostering Analytical and Critical Thinking Skills

This theme explained that PhET simulations assisted students in analyzing variables, making predictions, testing hypotheses, and reasoning. Simulations were persistently characterized by teachers as instruments that pushed students away from memorizing to reason and evaluate. The words of the teachers are the following:

“Students were in a position to anticipate results, challenge their hypotheses, assess the findings of simulations, and defend their findings.” (R1)

“Students were able to manipulate variables and see the results, acquiring critical thinking skills.” (R7)

“This assisted them in developing more reasoning, problem-solving, and decision-making.” (R5)

“Well, I used a simulation of plate tectonics, and students asked questions and improved their critical thinking because of unexpected results.” (R6)

These reactions from the respondents indicated that simulations stimulated interactive processes of thought like analysis, evaluation, and reasoning. Students did not passively receive information but were active and questioned the results and provided evidence to support the answers. One of the teachers claimed that their learners started posing questions of “what if ma’am” “what if ingon ani” and another teacher remarked that learners grew more self-assured when it came to describing their thinking. The results that were backed up by the previous studies indicated that interactive simulations helped to improve higher-order thinking, giving the learners the ability to manipulate variables and realize the cause-and-effect relationships. The PhET simulations were inquiry-based pedagogies that were congruent with constructivism educational concepts. It has also been claimed by research that simulations enable the reinforcement of critical thinking in case students get prompted to justify and elaborate on their findings (Pritchard, 2018; Simpson et al., 2021). This reinforced the observations given by the teachers that simulations encouraged more thorough consideration as opposed to memorization. The critical thinking theme was further brought out when teachers explained how students reacted when offered variable manipulation and real-time responses in simulations. Some of the teachers insisted on the fact that learners had the opportunity to develop hypotheses before having to modify the controls in the simulation. This is the same reasoning as scientific reasoning, in which the students already know something and make predictions beforehand, and then compare the predictions with the actual results. In situations where discrepancies were present, learners were forced to re-assess their assumptions. This mental unease is also congruent with constructivist theory, which proposes that a significant process of learning happens when the already established mental structures are disrupted and rearranged. Moreover, the records of the teachers contain some aspects of inquiry-based learning. Reflective thinking starts as soon as people get in doubt or uncertainty.

This reflective process is evidenced by the observation of R6 that the students were suspicious of the result that they had in the plate tectonics simulation. Accepting the results was not evident, as said by the teacher, as they were questioning them. This is in line with the Facione (2015) model of critical thinking that incorporates interpretation, analysis, evaluation, inference, and explanation (Facione, 2015). The fact that students are able to substantiate their findings as observed by R1 and R5 is indicative of a movement to the extent

of evaluation that cannot be comprehended. Such findings are also backed by the social constructivist perspective. Within the simulation activity, students were able to discuss predictions and support interpretations with others. Rationality was perfected through discussion. The simulation was used as an intermediary instrument that facilitated cognitive growth, as it was used in the classroom social environment. As such, the development of this theme is an intervention between the technological affordances and social learning.

Theme 2: Understanding is Enhanced by the Interaction of the Virtual and Traditional Tools.

The theme was used to describe how simulations, together with printed materials, discussions, experiments, and hands-on activities, enhanced the knowledge and critical thinking.

“In case of abstract processes, simulations are employed to visualize such processes, whereas traditional materials can be applied to support learning by real observation.” (R1)

“Printed materials allow the students to have more time to think, whereas simulations allow explaining concepts in a simplified way.” (R2)

“Simulations facilitate visualization of concepts, whereas the traditional tools enhance and entrench learning.” (R3)

“Simulation-based introduction of concepts followed by reinforcement of learning in the form of a hands-on activity.” (R7)

The teachers clarified that simulations could enable students to have a mental picture of concepts of an abstract nature, whereas conventional tools would allow students the time to think, reflect, and practice what was learned. In science, concepts like plate tectonics, chemical reactions, reaction rates, addition of vectors, and concepts of biology were cited as some of the areas where integration was able to work out. The feedback revealed that the concept learning was more relevant when students observed the concepts in simulations and then were supported in the form of conventional activities. In line with the research on blended learning, digital and traditional learning integration facilitated learning transfer. This proved that simulations were best applied in the context of structured instructional design as opposed to being applied alone. Akpan et al. (2021) concluded that a combination of conventional teaching methods with the application of virtual simulation leads to enhanced concept transfer compared to using a single technique. This empirical finding is consistent with the views of the teachers of the current research, who stated that instructional integration allows deeper learning and thinking. The integration theme was also present when the teachers kept on explaining sequencing strategies, but not the stand-alone use of technology. The interviews showed that simulations were not commonly applied without any other forms. Otherwise, teachers positioned them as preludes or exploration stages before they started thinking deeper into them using traditional means. The sequencing of instructions, as explained by the teachers, is in line with the recent studies of simulation-based learning environments. Research findings indicate that simulations conducted online provide maximum effectiveness when it is accompanied by discussion, written instructions, or practical exercises where a learner can solidify their knowledge. The studies on multimedia learning conditions show that students gain a deeper conceptual understanding when verbal explanation and reflective activity are used with visual representations (Makransky & Petersen, 2019). The stories of the teachers used in this paper portray this trend, whereby students initially saw phenomena in simulated form and subsequently held onto them by discussing and performing written or practical assignments. These results indicate that the use of digital and traditional learning materials can help to acquire a more consistent and significant cognition of scientific concepts. The teachers clarified that simulations could enable students to have a mental picture of concepts of an abstract nature, whereas conventional tools would allow students the time to think, reflect, and practice what was learned.

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Theme 3: Virtual and Traditional Methods are Supplementary to one another.

This theme was used to emphasize the position of teachers that simulations and traditional tools were complementary in terms of their advantages and disadvantages.

“The virtual simulations enable students to see and manipulate the abstract concepts whereas traditional tools allow students to have hands-on experiences.” (R1)

“The reason is that students learn concepts better through simulations, and deeper thoughts through the printed materials.” (R2)

“Traditional teaching stimulates the creation of concepts and PhET simulations introduce concepts into practice.” (R4)

Teachers did not consider simulations to be substitutes for conventional teaching but as an auxiliary means of learning. All the approaches had a separate instructive goal that reinforced the knowledge among the students. Digital simulations helped to give the visualization and interactive exploration, whereas the traditional strategies helped to support the discussions, reflection, and hands-on interactions. The same results were also documented in recent research that indicated that the use of simulations along with traditional instruction methods could improve conceptual knowledge and learners' interaction in the process of learning science (Banda & Nzabahimana, 2021). This theme arose as a result of the constant preaching of the teachers about the balance between digital and traditional practices.

Throughout the interviews, the respondents mentioned that the simulations enabled the students to visualize abstract processes, and traditional tasks enabled the students to interpret and implement the observations they made in the discussion and writing. The studies regarding technology-enhanced learning also show that digital tools become the most effective when they are combined with guided learning exercises and not when they are applied alone (Makransky & Petersen, 2019). With simulations coupled with reflective activities and teacher instructions, students can be in a better position to match visual representations to concept explanations. As the experiences of the teachers imply, meaningful learning takes place during the usage of digital simulations along with the traditional teaching strategy in a complementary way. Simulation is not meant to substitute traditional teaching but serves as an extra teaching tool that could be used to explore and visualize the concepts. Such an interaction/reflective combination of classroom activities and interactive technology supports the knowledge of the students and makes them more engaged in the process of discovering the scientific concepts.

Theme 4: Implementation is due to Technical and Resource Limitations.

This theme summed up the challenges that teachers had to go through in implementing simulations together with the traditional tools.

“Small access to technology, time and inability to integrate digital simulations.” (R1)

“The main challenge is technical in nature.” (R2)

“The absence of devices and the internet connection.” (R3)

“Hands-on learning is not in vain provided there is a good access to technology.” (R6)

“Time and resources balancing.” (R7)

Despite the overall positive attitudes towards simulations, the teachers also indicated that the adoption was frequently affected by the practical factors, such as a lack of the necessary infrastructure or devices, or poor internet connections. These were some of the factors that influenced the frequency and the effectiveness of simulations that could be applied in the process of instruction. The same issues have been reported in the research on technology-enhanced learning, where the lack of digital resources and infrastructural constraints were defined as typical obstacles to incorporating instructional technologies into the classroom (Liu et al., 2020; Saad et al., 2018). The implementation issues theme was based on the open-minded observations of the teachers concerning such contextual limitations and not on the dissatisfaction with the instructional tool. In interviews, respondents quoted problems with the availability of devices, their connection, time management, and pacing. These recurrent issues denote the reliance of the successful utilization of simulations, mainly, on the availability of technological possibilities, as well as, on the state of the learning environment.

Although these were experienced, classroom observations noted that teachers embraced adaptive measures, including the sharing of devices, collaboration in groups, and scheduled time so that simulations could be integrated into their lessons. The same trends have been cited in the research on technology integration, which reveals that teachers tend to come up with pragmatic ways to address resource scarcity without necessarily reducing the learning process. These results imply that the issues in this paper are systemic and not necessarily opposition to digital learning tools.

Theme 5: Provided to use Combined Methods, it was possible to improve the engagement and learning outcomes.

This theme was based on the observations of teachers who noted better critical thinking, engagement, and performance when using both methods.

“More frequent were the use of simulation by students who asked what if questions.” (R1)

“There is an increase in the score of students when the two methods are applied.” (R2)

“Students described ideas in a better way and connected them more effectively.” (R5)

“Without PHET discussion was boring, with PHET students were communicating and posing questions.” (R7)

The students who were involved in the simultaneous application of simulations and the traditional learning tools showed increased engagement, confidence, and reasoning skills in contrast to those students who used the traditional instruction only. The classroom discussion enhanced participation, clarity, and strength of responses in the form of analysis in response to questions by teachers. The theme was based on better engagement and learning based on these recurring observations in terms of the behavioral and cognitive changes in students. These observations are supported by recent studies on interactive learning environments. Instruction designed using simulation stimulates engagement and conceptual knowledge since the learners can manipulate variables, make their predictions, and interpret findings within realistic learning settings (Keller et al., 2018; Onyekuru, 2023). Students are more apt to gain confidence when discussing findings with peers when they access digital simulations directly and when discussing their findings with other students.

In this research, the experiences of the teachers are also comparable with the literature experiences where interactive simulations are mentioned to boost student curiosity, participation, and conceptual clarity. Through the integration of simulations, discussions, and reflections in the classroom environment, learners can actively work with scientific concepts and make certain observations in relation to the conceptualizations. Such conditions will help in creating a greater level of involvement and higher performance on science learning.

Triangulation Matrix of Data Sources

This triangulation was carried out with lesson plan designs and observed classroom practices as the simulations were implemented. This was to increase the validity of the findings. It was used by matching responses of interviews to lesson plans and classroom observations. The following table (2) summarizes the support of the themes in various sources of data.

Table 2. Triangulation Matrix of Data Sources

<i>Theme</i>	<i>Interview Data</i>	<i>Lesson Plan Evidence</i>	<i>Classroom Observation</i>
Critical Thinking	Teachers reported reasoning and justification	Guided inquiry questions included	Students asked “what if” questions
Integrated Instruction	Use of simulations with traditional tools	Simulation followed by hands-on tasks	Smooth transition between activities
Student Engagement	Teachers noted increased participation	Interactive activities planned	Active discussion and collaboration
Implementation Challenges	Reports of limited resources and time	Adjusted pacing and materials	Device sharing and time management
Learning Outcomes	Confidence and scores improvement	Alignment of Assessment	Explanations during oral is better

The analysis of the triangulation of the findings based on interview data, lesson plan documents, and classroom observations is shown in Table 2. Triangulation enhances credibility in qualitative inquiry by showing that the themes are backed by more than one piece of evidence, but not by a single source of data (Creswell & Poth, 2018). In this research, the themes that appeared based on the interview with the teachers were compared in a systematic manner with the reported instructional design and observed classroom practices to establish convergence and consistency.

Theme 1: Critical Thinking

There was a high level of conformity in all three sources. In interviews, R1 explained that students had the ability to foresee results, challenge their assumptions, test the evidence using simulations, and support their findings. Likewise, R7 responded that students were able to manipulate variables and observe what happened, whereas R6 stated that students were able to challenge outcomes that were not expected in a plate tectonics simulation. R5 also highlighted the fact that the simulation exercises contributed to the development of deeper reasoning, problem-solving, and decision-making. These utterances have higher-order thinking processes.

Investigating lesson plans, the instructional flow presupposed guided inquiry questions, such as asking students to predict the outcome before controlling the simulation, to justify the differences in the prediction and output, and to justify conclusions during recitation. These registered prompts are directly consistent with the description of prediction and justification given by R1. The lesson plans did not simply teach students to observe but explained and reasoned why, which proved that critical thinking was meant to be built into the instructional design.

Observations in the classroom were a clear confirmation of behavioral patterns, as described by the teachers. During classes, a teacher has said, "Ang students kay magtabi unsa ilahang mga expected results." and after such minutes finishing the experiment they refine their predictions based on the evidence they have seen. Such behaviors indicate an active thinking and reflective thinking in the process of learning. These results have also been found in simulation-based learning where learners evaluate outcomes and improve descriptions by exploring results through interactive methods (Makransky & Petersen, 2019; Cheng & Tsai, 2019). These activities were also supported by peer discussions, where conceptual knowledge was facilitated through collaboration and dialogue because learners could clarify ideas and reinforce arguments through peer discussions (Banda & Nzabahimana, 2021). The level of consistency of the responses given by the interviewees to the questions, lesson plans, and the observed behavior in the classroom supports the fact that critical thinking was effectively used as part of the learning process.

Theme 2: Integrated Instruction

Deliberate sequencing was found in triangulation. R1 clarified that abstract processes were visualized through simulations, whereas learning was reinforced using traditional material. R2 said that printed materials provide students with more time to think, and R7 said that he introduced concepts using simulations and solidified them using hands-on activities. These words imply that it was not used randomly, but through a planned combination.

These utterances were backed by lesson plans through the presentation of simulation exercises at the start of the lesson to explore concepts in a conceptual manner, and then laboratory work, worksheets, or guided discussions. As an example, a reaction rate exploration through simulation was then followed by a physical experiment on reaction changes. This pattern is a direct indication of the way described by R7 of introducing reinforcing.

Observations in classrooms gave good behavioral evidence of the patterns as explained by the teachers. It was observed that students would discuss potential results prior to running simulations, ask questions about the surprise results, and adjust their predictions when they analyzed the evidence. These actions show that there is active reasoning and reflective thinking in the learning process. The same has been observed in simulated learning settings where students interpret the findings and work out the explanations by interactively exploring the environment (Makransky & Petersen, 2019; Cheng & Tsai, 2019). Conceptual understanding was also supported in peer discussions during such activities since group conversation can facilitate learners to clear ideas and reinforce reasoning (Banda & Nzabahimana, 2021). The congruency of responses of the interview with lesson plans and classroom behavior observed supports the assertion that critical thinking was performed in the process of learning.

Theme 3: Student Engagement

Philosophical congruence was witnessed in interview data. R1 “explained that simulations can be visualized, whereas the traditional tools give a practical experience.” R2 indicated that “simulation is better at clarifying concepts, but printed materials promote critical thinking.” R4 characterized “traditional teaching as the construction of basic knowledge and simulations of concepts into practice.” These statements imply complement and not substitution.

The lesson plans showed that there was a balanced instructional design, with the use of simulation given a certain time within the wider lesson plans that, nevertheless, incorporated recitation, board explanations, and lab work. As expected, it was observed that the teachers guided the discussion during and after the simulation of use, and active instructional presence was maintained. Students were involved in online communication as well as traditional problem-solving.

This correspondence is consistent with the studies that have underlined the relevance of introducing technology alongside proper pedagogy and content in instruction. Research on technology-based learning demonstrates that successful teaching is possible when digital technologies are rationally integrated with pedagogical approaches that help learners to understand concepts (Tondeur et al., 2020). The reliability of this theme is enhanced by the consistency of the practices exhibited in the classroom and the views of the teachers.

Theme 4: Implementation challenges

Convergence was observed again through triangulation. R1 said that “it was caused by the lack of access to technology and time”, R2 said that “it was a technical issue”, and R3 said that “it was due to the lack of devices and the lack of internet access”. Such statements refer to structural constraints.

Modifications of lesson planning with a good contingency plan have been able to accommodate resource limitations. During observed sessions, device sharing was also observed, where students worked in groups because of the scarcity of computers. Teachers also used time wisely to make sure that simulation activities did not exceed class time. These findings support the recent research that found infrastructure and resource constraints to be one of the prevalent obstacles to technology adoption in classrooms (Liu et al., 2020). The congruence between the interviews, documentation, and observations suggests that the issues of implementation were based on the real classroom situation. In spite of these limitations, educators changed their teaching plans so that they could still use simulations in their classes.

In response to Theme 4, the researcher designed a contextualized implementation framework to make sure that the instructional output is viable, flexible, and responsive to real classroom conditions. These adaptations in procedures are direct reactions to the structural limitations as reported by participants in Theme 4. The contingency models that came forward as pedagogical translations of the lived experiences of the teachers were as follows. Station Rotation Model (With Limited Access to Devices). In classrooms with no more than three to six devices, teaching can be of a rotating format during a 60-minute lesson. The students are organized into four stations that are rotated. A rotation is about 12-15 minutes. It minimizes time wastage, maintains interest, and enhances team thinking. The rotational strategy endorses social constructive meaning and conceptual richness. The rotational approach supports social construction of meaning while maintaining conceptual depth. Time-Constrained Inquiry Model (In Compressed Instructional Periods) In situations with less instructional time, the teacher can pre-select particular simulation situations that are consistent with the desired learning goals. Instead of free discovery, students are asked to answer predictive questions that are focused and to explain the results in an organized discussion. Prolonged simulation manipulation can be given as guided homework with offline access or by means of recorded

demonstration clips. These strategies preserve the analytic thinking within the classroom setting.

Theme 5: Learning Outcomes

Triangulation was very validating. R7 said that “without PhET, the discussions were boring, but with simulations, students were socializing and asking questions.” R1 noted that “more questions were of the what-if type”, and R2 stated that “they obtained higher scores when both approaches were applied.” According to R5, “students described concepts in a better way and formed stronger associations”.

The reasoning-based type of assessment tasks was incorporated in the lesson plans instead of recall questions, which is lower-order thinking. It was observed that the students volunteered their responses, worked in groups, and explained concepts confidently during recitation. Students went beyond the minimum required answers, explaining their answers in a single session, which is a sign of cognitive engagement.

These results align with the recent studies that define student engagement as an active involvement, interest, and cognitive engagement in learning activities. Simulations and other interactive learning activities make students investigate, exchange ideas, and reflect on outcomes, which may result in more powerful knowledge and better grades (Keller et al., 2018; Onyekuru, 2023).

In general, the triangulation matrix indicates that the utterances in interviews were always backed by the recorded lesson plans and classroom practices. The fact that the data sources converge several times increases the credibility of the results and contributes to the uniformity of the themes identified in the research (Creswell & Poth, 2018). The themes are thus not only based on the perception of teachers, but also on recorded planning and experience in the classroom.

Conclusions

This study was both intellectually challenging and meaningful. Using lived experiences with teachers to observe instructional integration, not merely as a theory but as a practice that is formulated by the practicalities of classrooms. When hearing their stories, it is so sad to comprehend that being an integrator is not a matter of picking one or the other, virtual simulation or traditional tools, but rather it is about the way the teachers can balance the two carefully and address the needs of their students.

The actual commitment of the teachers was high through the interviews and classroom observations. They were resourceful and strong-willed in changing their instructional plans despite a lack of devices, poor internet connectivity, and time management. The ability of students to ask questions about results, discuss predictions, and justify them confirmed the importance of reflective teaching practices. It was also evident that technology does not turn a person into a critical thinker; instead, it is up to the deliberate instruction of a teacher that can turn tools into a learning experience. The theme identification and analysis of transcripts made the idea of phenomenological inquiry even more significant. In many instances, the narratives of reading teachers enable trends to come out in the descriptions of the teachers. The role of bracketing the assumptions and letting the voices of the participants inform the interpretation. This experience strengthened the understanding of this research as a careful, reflective, and ethical process. Moreover, this study has reshaped the perspective on instructional innovation. The practice of integration has been evident and can only be regarded as a trend when it is intentionally integrated with a sense of balance, reflection, and awareness of the context. The process of data collection and contextualization revealed that in the background of every instructional aid, there were teachers trying to make the learning process significant and learners trying to grasp the complicated ideas. This understanding had solidified this commitment by the researchers to conduct research respecting lived experiences and making contributions to practical changes in the educational practice.

The researcher also promoted the idea of teachers of STEM to combine PhET simulations with standard pedagogical techniques instead of employing simulations as a single tool, as traditional methods still remain a part of the argument. There should be simulations with guided questions, discussions, and practical work in order to encourage more profound thinking and the use of concepts. School administrators should provide adequate support for the use of simulations by ensuring stable internet connectivity, as it is one of the problems in the Philippine schools, and allowing sufficient instructional time for integrated activities would be good.

Curriculum developers may consider proposing a policy of PhET simulations and corresponding hands-on activities in crafting lesson guides. The school head would propose a training program that would help teachers design lessons that effectively combine simulations and traditional tools, with emphasis on promoting the critical thinking skills of students.

Future studies may replicate this research using a larger number of participants or in different school settings to strengthen triangulation and validate the findings. Researchers may employ mixed-methods or experimental designs to further examine the effect of PhET simulations on students' critical thinking skills using measurable outcomes. Future researchers may focus on lower grade levels, e.g., 7, 8, 9, 10, that are not covered in this study to determine whether similar results are observed. Future studies may address the limitations of this research by including classroom observations over a longer period, or pre- and post-assessments to provide a more comprehensive analysis of the critical thinking of the students.

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