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Enhancing Secondary Students' Conceptual Understanding through Virtual Reality-Integrated Guided Inquiry-Based Approach

Sweet Raiza Torres [1], Dhamie Rose Rebulado [2], Jerymi Amatorio [3], Mary Lourdes Ochoa [4], Ranel Dimitui [5], Marivette Miranda [6], Ronilo Antonio [7]

[1] Bulacan State University, Philippines, 0009-0004-6622-2965
[2] Bulacan State University, Philippines, 0009-0009-3843-2742
[3] Bulacan State University, Philippines, 0009-0004-2032-1917
[4] Bulacan State University, Philippines, 0009-0003-4498-2907
[5] Bulacan State University, Philippines, 0009-0000-8504-363X
[6] Bulacan State University, Philippines, 0009-0008-4429-6882
[7] Bulacan State University, Philippines, 0000-0002-2832-7203
* Corresponding author: Ronilo Antonio (ronilo.antonio@bulsu.edu.ph)

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Abstract

Addressing persistent scientific misconceptions requires learning environments that make abstract phenomena visible, interactive, and conceptually meaningful. This study explored the effectiveness of a virtual reality (VR)-integrated guided inquiry-based learning module in enhancing Grade 7 students' conceptual understanding of heat and temperature—topics often associated with misconceptions. Conducted in a Philippine public school, the quasi-experimental study involved 32 students who completed pretests, posttests, and reflective questionnaires. Results indicated a statistically significant improvement in posttest scores ($p < 0.001$), demonstrating that the VR-enhanced approach effectively addressed conceptual gaps. Qualitative findings revealed increased engagement, improved visualization of scientific phenomena, and greater motivation to learn. Students noted that VR made abstract concepts more tangible compared to traditional methods. However, some reported mild physical discomfort, such as dizziness and eye strain, pointing to the need for ergonomic consideration in VR use. The study highlights the pedagogical value of VR in science education, offering immersive, inquiry-driven learning experiences that foster deeper understanding while emphasizing the need for thoughtful implementation to ensure student well-being.

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Introduction

The evolving landscape of education continues to shift toward fostering deeper, more meaningful learning experiences, moving beyond the passive absorption of information toward nurturing conceptual understanding. This shift is especially critical in science education, where foundational concepts shape how learners interpret the world and influence their future academic and career trajectories (Bransford et al., 2020; National Academies of Sciences, Engineering, and Medicine, 2018). At the heart of this challenge lies the interplay between students' prior knowledge and the new ideas introduced in the classroom. Learners often arrive with intuitive beliefs formed through personal experience, cultural context, or everyday observation. While such preconceptions may initially help students make sense of phenomena, they often conflict with established scientific explanations, creating cognitive dissonance that impedes learning (Vosniadou, 2019).

This tension between intuitive belief and scientific fact can lead to confusion, frustration, and resistance to learning, especially when instruction fails to bridge these conceptual gaps. Formal explanations that contradict personal experience can stifle curiosity, reduce engagement, and hinder motivation to explore. Over time, this cycle reinforces misconceptions, erodes confidence, and widens the gap between students' mental models and scientific understanding (Jeharut et al., 2020; Wichmann et al., 2003). When left unaddressed, such misconceptions pose serious threats to students' progression in science learning, particularly in physics, where abstract concepts require high cognitive demand and deep comprehension. Misunderstandings also contribute to broader scientific illiteracy, limiting students' ability to apply knowledge to real-world problems (Osborne & Pimentel, 2023).

Globally, science education has transitioned toward inquiry-driven, constructivist approaches that cultivate critical thinking and problem-solving rather than rote memorization. This pedagogical shift aligns with calls for a scientifically literate citizenry—an urgent need in the face of complex global challenges such as climate change, public health crises, and technological advancement (National Science Board, 2015). However, persistent misconceptions remain a key barrier to achieving this goal. Students often perceive scientific knowledge as static rather than dynamic and evolving, which limits their engagement and hinders their appreciation of science as a process of inquiry (Schmidt, 2011; Songer & Linn, 1991).

In the Philippine educational context, significant reforms have sought to make science learning more hands-on, contextualized, and inquiry-based. Despite these efforts, persistent misconceptions, particularly in physics, continue to obstruct student understanding. Filipino students, like many of their international peers, struggle with mechanisms such as conduction, convection, and radiation—core principles in understanding both everyday phenomena and larger scientific issues such as climate change (Villarino, 2023). These difficulties reflect broader limitations in science learning and pose obstacles to the national agenda for STEM advancement (Department of Education, 2013; National Economic and Development Authority, 2020). Moreover, conceptual misunderstandings in thermal physics hinder students' ability to understand environmental science issues, such as global warming, where accurate knowledge of heat transfer is essential (Chu et al., 2012; Georgiou & Sharma, 2010).

Recent technological innovations offer promising solutions to these learning challenges. Virtual Reality (VR) has emerged as a powerful tool for enhancing science education by providing immersive, interactive experiences that allow students to visualize and manipulate abstract concepts in safe and engaging environments. VR enables students to observe phenomena—such as molecular behavior during heat transfer—that are otherwise invisible or too dangerous to replicate in a typical classroom. Studies show that VR enhances engagement, supports spatial reasoning, and improves conceptual retention (AlAli & Wardat, 2024; Choudhury, 2024; Huang et al., 2021). Additionally, it fosters collaboration, communication, and deeper inquiry, aligning with essential 21st-century competencies (Wu et al., 2023).

When paired with Guided Inquiry-Based Approaches (GIBA), VR becomes even more effective. Guided inquiry scaffolds students' cognitive processes by structuring exploration around critical questions, hands-on experiences, and reflective tasks. This combination promotes self-directed learning while ensuring instructional support, which is essential when addressing entrenched misconceptions (Huang et al., 2019; Winn, 2016). The integration of VR and GIBA represents a pedagogical synergy that can bridge the conceptual gaps between students' intuitive beliefs and scientific principles.

This study investigates the effectiveness of a Virtual Reality-integrated Guided Inquiry-Based Approach in addressing Filipino Grade 7 students' misconceptions about heat and temperature. The intervention aims to uncover, confront, and correct these misconceptions through experiential learning and structured inquiry. In doing so, the research contributes to the broader goal of cultivating scientific literacy and empowering learners to engage critically with real-world issues such as climate change. Findings from this study are expected to inform instructional design, curriculum development, and policy efforts aimed at enhancing the quality and equity of science education in the Philippines.

Literature Review

Misconceptions in Heat and Temperature

Students frequently enter science classrooms with deeply rooted intuitive conceptions about heat and temperature that conflict with scientific explanations. These misconceptions often stem from everyday experiences and language use, leading learners to believe, for instance, that heat is a substance contained within objects or that temperature directly measures the amount of heat present (Alwan, 2011; Salame et al., 2025). Such alternative conceptions are particularly problematic in thermodynamics, where abstract processes such as molecular motion, energy transfer, and equilibrium are not directly observable.

Research consistently shows that misconceptions about heat and temperature are highly resistant to change when instruction relies on traditional, lecture-based approaches (Wichmann et al., 2003; Jeharut et al., 2020). Without explicit opportunities to confront and reconstruct faulty mental models, students tend to assimilate new information superficially while retaining incorrect underlying beliefs. These persistent misconceptions impede students' ability to understand more advanced scientific concepts and limit their capacity to apply knowledge to real-world phenomena such as climate change, energy conservation, and environmental sustainability (Chu et al., 2012; Georgiou & Sharma, 2010).

Conceptual change-oriented instructional strategies have therefore been emphasized as essential in addressing misconceptions in thermal physics. Such approaches intentionally surface students' prior knowledge, create cognitive conflict, and guide learners toward scientifically accurate explanations through structured experiences and reflection (Turgut & Gurbuz, 2014; Duit, 2012). Effective instruction must go beyond content delivery and actively engage learners in reconstructing their conceptual frameworks.

Conceptual Understanding in Science Education

Conceptual understanding in science involves more than the acquisition of factual knowledge; it requires learners to organize ideas into coherent mental models that can be applied flexibly across contexts (Bransford et al., 2020). According to Duit (2012), meaningful learning occurs when students integrate new concepts with existing knowledge structures and revise inaccurate beliefs. However, large-scale studies indicate that traditional science instruction has had limited success in fostering deep conceptual understanding, particularly in abstract domains such as physics (Ruiz-Primo et al., 2011; Mengistu et al., 2022).

Emerging scholarship emphasizes the need for active, learner-centered pedagogies that promote inquiry, reasoning, and reflection. Approaches that encourage students to explore phenomena, test ideas, and articulate explanations have been shown to improve conceptual clarity and long-term retention (Vaiopoulou et al., 2023; Widiyatmoko & Shimizu, 2018). Diagnostic assessments and reflective tools further support conceptual development by helping learners identify misconceptions and monitor their own understanding (Ruiz-Primo et al., 2011).

In this context, addressing misconceptions about heat and temperature requires instructional environments that support visualization, experimentation, and guided sense-making. These requirements have driven growing interest in technology-enhanced learning environments that can make invisible processes observable and manipulable.

Virtual Reality in Science Education

Virtual Reality (VR) has emerged as a powerful instructional technology capable of transforming science learning through immersive and interactive experiences. Unlike traditional simulations or static visualizations, VR enables learners to explore three-dimensional environments, manipulate variables, and observe dynamic processes from multiple perspectives. In science education, VR has been shown to enhance engagement, spatial reasoning, and conceptual understanding, particularly for abstract and complex phenomena (Huang et al., 2021; AlAli & Wardat, 2024; Choudhury, 2024).

VR is especially effective in teaching thermodynamics concepts, as it allows students to visualize molecular motion, energy transfer, and temperature changes that are otherwise inaccessible in conventional classrooms

(Pfotenhauer & Gagnon, 2021; Liu et al., 2020). By externalizing invisible processes, VR supports the construction of accurate mental models and facilitates conceptual change (Durukan et al., 2020; Reen et al., 2025). Studies further indicate that immersive environments foster motivation, curiosity, and sustained attention, aligning with the development of 21st-century competencies such as critical thinking and scientific inquiry (Wu et al., 2023).

Guided Inquiry-Based Learning and VR Integration

Guided Inquiry-Based Learning (GIBL) is grounded in constructivist learning theory, which posits that learners actively construct knowledge through experience, exploration, and reflection. Unlike open inquiry, guided inquiry provides structured scaffolding that supports learners as they investigate phenomena, formulate explanations, and refine understanding—an approach particularly suitable for novice learners and complex content areas (Winn, 2016; Huang et al., 2019).

When integrated with VR, guided inquiry offers a pedagogical synergy that enhances conceptual understanding while mitigating potential cognitive overload. VR provides immersive experiences, while guided inquiry structures learners' interactions through targeted questions, prompts, and reflective tasks (Fabris et al., 2019). This combination has been shown to promote deeper cognitive processing, encourage metacognitive awareness, and support conceptual change by explicitly linking experience with scientific explanation.

Beyond VR, simulation-based learning environments, including computer-based and mobile simulations, have demonstrated effectiveness in correcting misconceptions related to heat transfer when paired with scaffolding and inquiry prompts (Xie, 2012; Islam & Chua, 2025). Mobile applications further contribute by offering personalized and gamified learning experiences that enhance motivation and learner engagement (Karabatzaki et al., 2018; Chuchu & Ndoro, 2019; Rocque, 2022). Nevertheless, VR remains distinct in its capacity to provide embodied and spatially immersive experiences, which are particularly valuable for understanding microscopic and dynamic thermal processes.

Research Gap and Rationale

While international research provides strong evidence supporting VR-integrated inquiry-based learning, localized studies examining its effectiveness in addressing heat and temperature misconceptions among junior high school students remain limited. In the Philippine context, few empirical investigations have explored how immersive technologies combined with guided inquiry can enhance conceptual understanding in thermal physics, despite persistent learning difficulties in this domain (Villarino, 2023). This study addresses this gap by introducing LIKNAYHUSAY, a culturally responsive VR-integrated guided inquiry intervention designed to uncover, confront, and correct misconceptions about heat and temperature among Filipino Grade 7 learners. By examining both conceptual gains and student experiences, the study contributes empirical evidence to inform instructional design, curriculum development, and policy initiatives aimed at strengthening science education through immersive and inquiry-driven pedagogies.

Research Questions

This study aims to address misconceptions and enhance conceptual understanding of heat and temperature through a VR-integrated Guided Inquiry-Based Approach. Specifically, it answers the following questions:

1. How may the Virtual Reality Science Simulation-based module be developed and validated?
2. How may students' misconceptions and conceptual understanding of heat and temperature be described prior to and after exposure to the VR science simulation?
3. Is there a significant improvement in students' conceptual understanding of heat and temperature after exposure to the VR science simulation?
4. What are the students' perceptions, insights, and experiences during the VR-based inquiry learning?

Methodology

Research Design

This study employed a quasi-experimental, mixed-methods design to examine the effectiveness of a VR-integrated Guided Inquiry-Based Approach in addressing students' misconceptions and enhancing conceptual understanding of heat and temperature. The quantitative component involved pre- and post-tests to measure learning gains, offering objective data on the intervention's impact. The qualitative component consisted of interviews that explored students' misconceptions and perceptions in depth. A quasi-experimental approach was used due to the absence of random assignment, allowing for practical implementation in real classroom settings while ensuring valid evaluation of the instructional intervention (Shadish et al., 2002).

Research Locale and Participants

The study was conducted with 32 Grade 7 students from a public school in Pulilan, Bulacan, Philippines, during the 2024–2025 academic year. Participants were selected through convenience sampling, based on availability, consent, and proximity. These students were chosen because heat and temperature are key topics in the Grade 7 science curriculum under the Department of Education's MATATAG Curriculum, ensuring relevance and curricular alignment. This allowed for an accurate assessment of conceptual understanding and common misconceptions related to heat transfer. The research was carried out in person, with informed consent secured from the school, parents, and student participants. The school was selected for its openness to research-based instructional innovations, supporting the study's aim of exploring effective strategies to improve science learning outcomes.

Research Instruments

Checklist for Development and Validation of the VR-Integrated Guided Inquiry Based Approach

To ensure the systematic development and implementation of the instructional intervention, a Checklist for Development and Validation of the VR-Integrated Guided Inquiry-Based Approach (GIBA) was utilized. It served as both a developmental and evaluative tool, guiding the creation of the VR Science Simulation and ensuring its alignment with pedagogical principles and curriculum standards. The checklist assessed four key domains: User Experience & Engagement, Conceptual Understanding & Misconceptions, Instructional Design & Integration, and Reflection & Evaluation. A 4-point Likert scale was used to measure the level of agreement with each item. The User Experience & Engagement component evaluated the accessibility, intuitiveness, and interactivity of the simulation, focusing on its ability to engage learners through immersive features. The Conceptual Understanding & Misconceptions domain reviewed how effectively the simulation addressed common misconceptions related to heat and temperature, ensuring that scientific explanations were accurate and inquiry-driven. The Instructional Design & Integration section examined the coherence of the content and its alignment with the MATATAG Curriculum competencies, assessing how well the simulation was embedded in the learning experience. Lastly, the Reflection & Evaluation component explored how the simulation supported learners' ability to reflect on their understanding and monitor their progress. The validation process involved expert review by nine (9) science content and curriculum specialists, one (1) language validator, and one (1) software validator. Their feedback guided the refinement of the simulation, ensuring its instructional quality, scientific accuracy, and effectiveness in achieving the intended learning outcomes.

Adapted and Modified Content Evaluation Rating Sheet (AMCERS)

To ensure the quality and credibility of the developed instructional module, the study utilized the Adapted and Modified Content Evaluation Rating Sheet (AMCERS). This instrument was based on the standards outlined in DepEd Memorandum No. 167, s.2021 – Enclosure No. 4.1, and was tailored to evaluate the content validity of the VR-integrated guided inquiry learning material. The researcher adapted the criteria and modified the scoring system into a 4-point Likert scale to measure the level of agreement across key content indicators. AMCERS includes six sections that holistically assess instructional quality. The Learning Competencies section examines the module's alignment with DepEd-prescribed learning competencies and evaluates the logical progression of content relative to the cognitive level of Grade 7 learners. The Instructional Design and Organization section reviews the effectiveness of lesson sequencing, content appropriateness, and the integration of strategies that promote engagement, such as overviews, organizers, puzzles, and games. The Readability section ensures that vocabulary, sentence structure, and paragraph organization are suitable for students' comprehension levels and that the module presents ideas clearly and cohesively. The Assessment and Evaluation section focuses on the presence and clarity of tools for gauging learner progress. It examines the alignment between assessments and competencies, the inclusion of varied assessment types, and the clarity of rubrics and instructions. Through AMCERS, the instructional material was rigorously evaluated to confirm its relevance, coherence, and effectiveness in supporting the intended learning outcomes.

Heat and Temperature Conceptual Understanding Test (HTCUT)

To assess students' conceptual understanding of heat and temperature, the researchers developed the Heat and Temperature Conceptual Understanding Test (HTCUT), administered as both a pre-simulation and post-simulation assessment. The instrument was designed to measure students' baseline knowledge prior to the intervention and evaluate learning gains following exposure to the VR Science Simulation. It consisted of 20 multiple-choice questions, each with four answer options and one correct response, covering topics such as thermal conductivity, the distinction between heat and temperature, heat absorption by materials, and real-world applications of heat transfer. The test included a mix of lower- and higher-order thinking skills, and the maximum score was 20.To ensure validity, the HTCUT was reviewed by two science education experts and one language expert for content accuracy, clarity, and appropriateness. The test yielded quantitative data used to determine the effectiveness of the VR-integrated Guided Inquiry-Based Approach in improving students' conceptual understanding of heat and temperature.

Student Reflective Questionnaire (SRQ)

After the intervention, students completed the Student Reflective Questionnaire (SRQ), which was designed to capture qualitative data related to engagement, motivation, and conceptual understanding based on their experiences with the simulation. This feedback tool allowed students to express their thoughts and reflections on their learning journey during the VR intervention. The SRQ included open-ended questions that encouraged students to freely share their experiences, challenges, and suggestions for improvement. This enabled the researchers to gather rich, descriptive feedback, helping to identify areas for improvement, such as specific student difficulties or aspects of the VR simulation that could be enhanced. This qualitative data complemented the quantitative data collected from the Heat and Temperature Conceptual Understanding Test (HTCUT), providing a more holistic view of the intervention's impact on students' learning.

Components of Student Reflective Questionnaire (SRQ)

To complement the quantitative data gathered from the Heat and Temperature Conceptual Understanding Test (HTCUT), the Student Reflective Questionnaire (SRQ) was administered after the intervention to collect qualitative feedback on students' experiences with the VR Science Simulation. The SRQ was designed to capture student reflections on engagement, motivation, immersion, and technical challenges, providing deeper insights into how the intervention influenced their learning process. The questionnaire consisted of open-ended questions, allowing students to freely articulate their thoughts, challenges, and suggestions for improvement. This qualitative data offered a richer understanding of the VR learning environment and helped identify factors that either enhanced or hindered conceptual understanding. The SRQ was organized into three key components. The Engagement and Motivation section explored how the simulation influenced students' interest and enjoyment in learning about heat and temperature. The Immersion and Presence section assessed students' sense of being part of the virtual environment and how the simulation sustained their attention. The Technical Issues section addressed students' experiences with the functionality and compatibility of the VR tool, identifying any problems that may have affected their learning.

Teaching Intervention

The teaching intervention was anchored on the 7E Instructional Model and implemented through a structured integration of the VR Science Simulation into classroom discussions. As shown in Figure 1, the flow began with the "What I Need to Know?" phase (Elicit), which clarified the skills and competencies students were expected to achieve, setting a clear learning focus. The "Activating Schema" phase (Engage) consisted of two parts: Part A activated prior knowledge about heat and temperature, while Part B encouraged students to recall their previous understanding and identify existing misconceptions. This was followed by the "VR-AGHAM Inquiry Task" (Explore), where students engaged in a guided inquiry using the VR simulation. In this phase, they manipulated different materials and variables to explore heat and temperature concepts within a safe, immersive environment, thereby linking prior knowledge with new learning.

Next, in the "Virtual Reality Temperature Trek" (Explain), students participated in deeper conceptual inquiry, examined the mechanisms of heat transfer, and began addressing the misconceptions identified earlier. The "Digging Deeper!" phase (Explain) further provided structured discussions to solidify understanding by connecting VR experiences with scientific explanations. In the "Extend Your Thermal Knowledge!" phase (Elaborate), students applied their conceptual understanding to real-world contexts through targeted activities, reinforcing key ideas and addressing lingering misconceptions. This was followed by the "Learning Check!" phase (Evaluate), where various formative assessments were conducted to measure mastery of heat and temperature concepts. Finally, the "Debrief the Thermal Experience!" phase (Extend) encouraged students to reflect on their learning, integrate new knowledge, and consider its application in novel situations. This comprehensive approach aimed to foster deep, lasting understanding while leveraging the immersive and interactive strengths of VR to support inquiry-based learning.

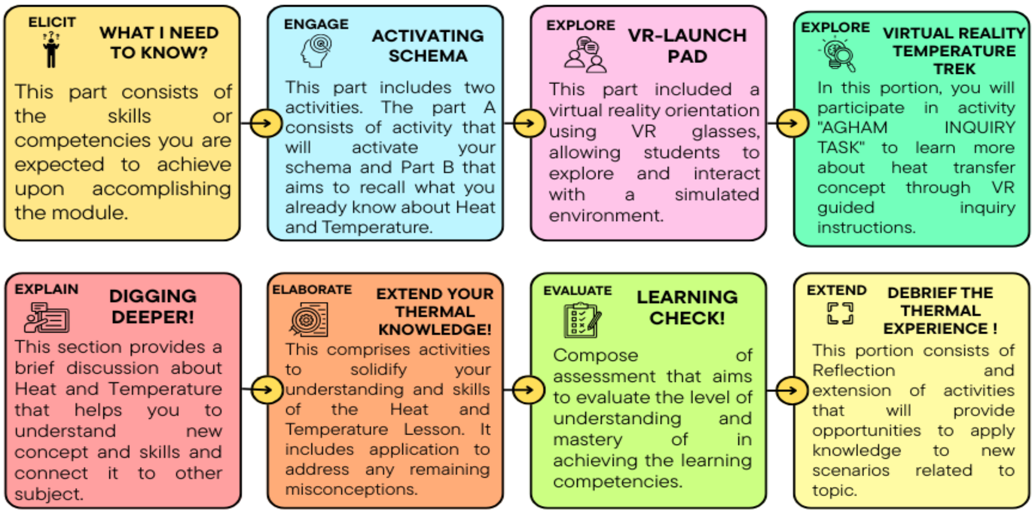

Figure 1. Implementation of VR Science Simulation in Class Discussions using 7E's Framework

Research Procedures

This study employed the ADDIE instructional design model to systematically develop, implement, and evaluate the VR-Integrated Guided Inquiry-Based Approach (GIBA), as presented in Figure 2. ADDIE was selected for its structured yet flexible framework, which supports iterative refinement and alignment between instructional design, implementation, and learning outcomes (Smith & Johnson, 2019).

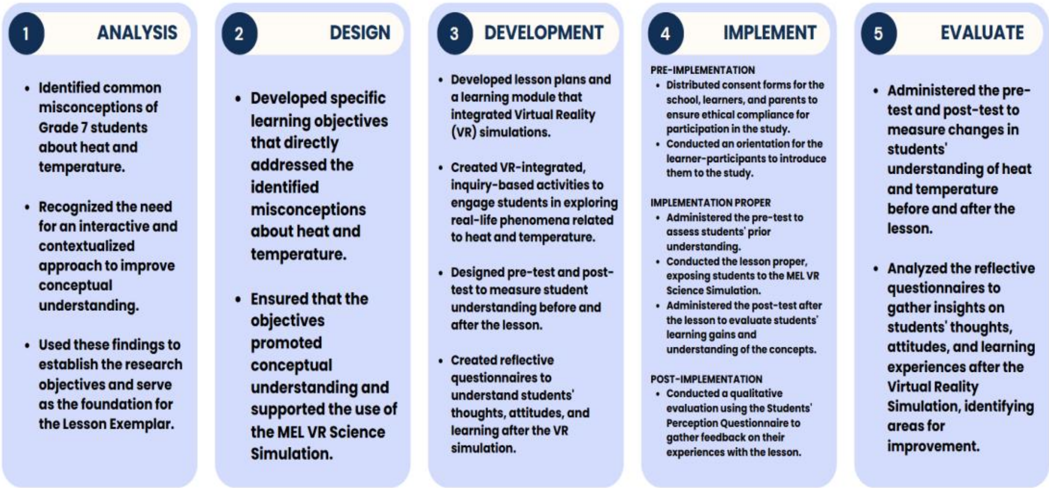

Figure 2. ADDIE Instructional Model

During the Analysis phase, the researchers identified the target population and examined prevalent misconceptions about heat and temperature among Grade 7 students through curriculum review and diagnostic data. This phase established the need for an interactive, inquiry-based, and immersive instructional strategy, which guided the formulation of research objectives and instructional planning.

The Design phase focused on developing learning objectives aligned with the MATATAG Science Curriculum and structuring VR-integrated inquiry lessons to promote conceptual change. Instructional sequencing followed inquiry-based principles, while assessment and validation instruments—including the Heat and Temperature Conceptual Understanding Test (HTCUT) and Alternative Misconceptions Conceptual Evaluation Rubric Scale (AMCERS)—were designed to measure learning outcomes.

In the Development phase, the VR Science Simulation module and supporting instructional materials were created and refined. Content experts, curriculum specialists, and validators reviewed the materials to ensure scientific accuracy, pedagogical soundness, clarity, and alignment with learning objectives. Guided inquiry tasks were embedded within the VR environment to scaffold students' exploration, reasoning, and reflection.

Figure 3. During-Implementation Flowchart

The Implementation phase involved delivering the VR-integrated guided inquiry lessons to Grade 7 students in a public secondary school (see Figure 3). Instruction was conducted in person over four instructional days, during which students engaged in structured inquiry tasks, VR simulations, discussions, and reflective activities. Ethical protocols were strictly observed, including approvals from the Department of Education and school administrators, as well as informed consent from parents and students.

Finally, the Evaluation phase assessed the effectiveness of the intervention using a mixed-methods approach. Pre- and post-tests (HTCUT) were administered to measure changes in students' conceptual understanding, while the Student Reflective Questionnaire (SRQ) gathered qualitative insights into learners' experiences, perceptions, and remaining misconceptions. Quantitative and qualitative data were analyzed to evaluate instructional effectiveness and inform further refinement of the VR-integrated guided inquiry approach.

Data Analysis

This study gathered both quantitative and qualitative data to evaluate the effectiveness of a VR-integrated Guided Inquiry-Based module on students' conceptual understanding of heat and temperature. Expert validation of the VR module was conducted, with Cronbach's Alpha confirming high internal consistency ($\alpha \geq 0.80$), and qualitative ratings affirming its pedagogical soundness and curriculum alignment. Students' misconceptions and understanding were assessed using the Heat and Temperature Conceptual Understanding Test (HTCUT). Pre- and post-test scores were analyzed using means, standard deviations, and mean percentage scores (MPS), while the Wilcoxon signed-rank test determined significant learning gains. To complement these findings, qualitative data from the Student Reflective Questionnaire (SRQ) underwent thematic analysis. Emerging themes, such as engagement, conceptual clarity, and technical challenges, highlighted how the VR environment enhanced visualization and motivation while revealing areas for improvement. The integrated findings demonstrate that VR-supported guided inquiry promotes both cognitive and affective learning gains, effectively addressing persistent misconceptions in thermal physics.

Results and Discussion

Development of VR Integrated Guided Inquiry Based Approach Pedagogy

To address students' misconceptions and enhance conceptual understanding, this study employed a researcher-developed VR-Integrated Guided Inquiry-Based learning module as the primary instructional tool. The module was aligned with the DepEd Grade 7 MATATAG Science Curriculum and underwent expert validation in terms of content accuracy, pedagogical soundness, technology integration, and language appropriateness. It served as the instructional backbone of the intervention, providing structured inquiry activities, immersive VR experiences, and clear facilitation guidelines to support meaningful learning.

The development of the pedagogy followed a systematic and curriculum-driven process. Least mastered physics competencies were first identified through diagnostic assessments to ensure that the intervention targeted conceptually challenging topics. Learning objectives were then formulated in alignment with curriculum standards, emphasizing scientific reasoning and conceptual mastery. To support immersive learning, the MEL VR Science Simulation platform was integrated through an approved free trial, ensuring ethical and institutional compliance.

The lesson exemplar was designed using the 7E instructional model (Elicit, Engage, Explore, Explain, Elaborate, Evaluate, Extend), with VR activities embedded across inquiry phases to stimulate curiosity, enable interactive exploration, and support conceptual change. Guided inquiry strategies were integrated throughout the module, scaffolding students from virtual experimentation to abstract reasoning through structured prompts, reflection questions, and data-driven tasks. Simulations allowed learners to manipulate variables, observe molecular behavior, and test hypotheses within a safe and engaging environment.

To ensure instructional quality, the module was reviewed by subject matter experts, master teachers, and curriculum specialists. Their feedback informed revisions that enhanced clarity, refined guiding questions, corrected scientific inaccuracies, and strengthened real-world connections. A final quality check confirmed the coherence, functionality, and classroom readiness of all instructional materials, including teacher guides, rubrics, and reflection tools. This structured development process ensured that the VR-integrated guided inquiry pedagogy effectively supported conceptual understanding while maintaining pedagogical integrity and learner engagement.

Science Experts Validation of VR-Integrated Guided Inquiry Based Learning Module

Table 1 presents the consolidated average ratings from expert validators evaluating the Virtual Reality-Integrated Guided Inquiry-Based Approach Module for Heat and Temperature, specifically in terms of its integration of virtual reality. The evaluation focuses on four key domains related to VR integration: User Experience and Engagement, Conceptual Understanding and Misconception, Instructional Design and Integration, and Reflection and Evaluation. These ratings reflect the overall effectiveness and quality of the module in supporting meaningful learning through the integration of virtual reality. Each criterion was assessed in terms of its quality and effectiveness using mean (M), standard deviation (SD), and the corresponding verbal interpretation (VI).

The highest mean scores were recorded in the domains of User Experience and Engagement, and Instructional Design and Integration, both with a mean of 3.878 and a standard deviation of 0.308, receiving a verbal interpretation of "Very Evident." These results indicate that the module is both highly engaging and user-friendly, while also exhibiting strong instructional design and coherence. The next highest domain, Conceptual Understanding and Misconception, received a (M = 3.848, SD= 0.311), also interpreted as *"Very Evident."* This demonstrates the module's effectiveness in promoting accurate conceptual learning and addressing students' misconceptions related to heat and temperature. The domain of Reflection and Evaluation, although slightly lower, still attained a high rating of (M = 3.818, SD = 0.345) and a verbal interpretation of *"Very Evident",* indicating that the module effectively supports learners in evaluating their understanding and recognizing areas that need improvement. The overall average rating across all four domains (M = 3.855, SD = 0.318), which also corresponds to a *"Very Evident"* interpretation. These consistently high ratings across domains confirm strong agreement among expert validators regarding the module's quality and effectiveness. The minimal range of standard deviations (0.308 to 0.345) further underscores the high level of consistency and reliability in their evaluations.

Table 1. Summary of Validators' Averaged Ratings for the Virtual Reality Integrated Guided Inquiry Based Approach Module for Heat and Temperature (Virtual Reality Integration)

Criteria	Mean	Standard Deviation	Verbal Interpretation
User Experience and Engagement	3.878	0.308	VE
Conceptual Understanding and Misconception	3.848	0.311	VE
Instructional Design and Integration	3.878	0.308	VE
Reflection and Evaluation	3.818	0.345	VE
AVERAGE	3.855	0.318	VE

Note: Verbal Interpretation of the Mean 3.26 - 4.00 Very Evident (VE), 2.51 - 3.25 Moderately Evident (ME), 1.76 - 2.50 Slightly Evident (SE), 1.00 - 1.75 Not at All Evident (NE)

Table 2 provides a comprehensive summary of the average ratings given by expert validators for the Virtual Reality-Integrated Guided Inquiry-Based Approach Module on Heat and Temperature, focusing specifically on its effectiveness as a learning resource. The evaluation was based on four key criteria: Assessment and Evaluation, Instructional Design and Organization, Content, and Readability. Each was assessed using the mean (M), standard deviation (SD), and corresponding verbal interpretation (VI). Among these, Assessment and Evaluation received the highest mean score (M = 3.927, SD = 0.100), indicating strong and consistent agreement among validators that this component is "*Very Evident*," and affirming the module's strength in measuring student learning and outcomes. Closely following was Instructional Design and Organization with a (M = 3.909, SD = 0.215), also interpreted as "*Very Evident*." This suggests that the module's instructional framework is logically structured and effectively organized, supporting smooth learning progression. The Content criterion obtained a M = 3.886, SD = 0.205), also receiving a "*Very Evident*" interpretation, reflecting that the information presented is accurate, relevant, and well-aligned with the intended learning goals. Although Readability received the lowest mean score (M = 3.836, SD = 0.265), it still met the "*Very Evident"* threshold, indicating that the module is generally clear and understandable, with minor areas that could benefit from enhanced clarity for even greater accessibility.

Table 2. Summary of Validators' Averaged Ratings for the Virtual Reality Integrated Guided Inquiry Based Approach Module for Heat and Temperature (Learning Resource)

Criteria	Mean	Standard Deviation	Verbal Interpretation
Content	3.886	0.205	VE
Instructional Design and Organization	3.909	0.215	VE
Readability	3.836	0.265	VE
Assessment and Evaluation	3.927	0.100	VE
AVERAGE	3.889	0.196	VE

Note: Verbal Interpretation of the Mean 3.26 - 4.00 Very Evident (VE), 2.51 - 3.25 Moderately Evident (ME), 1.76 - 2.50 Slightly Evident (SE), 1.00 - 1.75 Not at All Evident (NE)

Overall, the module achieved a strong average (M = 3.889, SD = 0.196) across all domains, with a consistent verbal interpretation of *"Very Evident,"* signifying its high level of acceptability and effectiveness in facilitating instruction on heat and temperature through the integration of virtual reality and guided inquiry-based strategies. The narrow range of standard deviations (0.100 to 0.265) further emphasizes the validators' consensus and confidence in the module's quality. The convergence of high average ratings and low variability supports the conclusion that the module effectively leverages VR technology to deliver a comprehensive, engaging, and pedagogically sound learning experience.

Table 3 presents the summarized inter-rater reliability statistics of Virtual Reality Integrated Guided Inquiry-Based Approach Module for Heat and Temperature (VR-GIBA) as regards to Virtual Reality Integration and Learning Module. This evaluation was done to assess the internal consistency of the module's assessment and the Virtual Reality evaluation components.

Table 3. Inter-rater Reliability Statistics of Experts of VR-Integrated Guided Inquiry Based Approach in Virtual Reality Integration as regards to Learning Module

N of Items	Cronbach's Alpha	Internal Consistency
40	0.932	Excellent

Note: a≥0.9(Excellent), 0.9≥ a ≥0.8 (Good), 0.8 ≥ a ≥0.7 (Acceptable), 0.7 ≥ a ≥0.6 (Questionable), 0.6 ≥ a ≥ 0.5 (Poor), 0.5 ≥ a (Unacceptable)

With 40 items assessed, the Cronbach's Alpha was calculated at 0.932, indicating excellent internal consistency among the raters. This suggests a very high level of agreement among the experts in evaluating the quality and effectiveness of the module across various domains. Based on established statistical guidelines, a Cronbach's Alpha value equal to or greater than 0.9 reflects excellent reliability, demonstrating that the evaluation tool is highly consistent and dependable. This strengthens the credibility of the findings related to the module's overall quality and reinforces its appropriateness for instructional use.

Quantitative Findings

Table 4 presents the results of both the pretest and posttest administered to 32 students (N = 32) on the topic of Misconception and Conceptual Understanding of Heat and Temperature.

Table 4. Mean and Standard Deviation on Pretest and Posttest Scores on the Misconception and Conceptual Understanding on Heat and Temperature

	N	N of Items	Mean	SD	MPS	VI
Pre-test	32	20	5.625	1.879	28.125	Low
Post test	32	20	17.438	1.865	87.188	High

Note: MPS interpretation, 0-25 (Very Low), 26-49 (Low), 50-74 (Moderate), 75-89 (High), and 90-100 (Very High).

The test consisted of 20 items designed to assess students' conceptual grasp of the topic. In the pretest, the results show a Mean Percentage Score (MPS) of 28.12% (M = 5.625, SD = 1.879), which falls under the "Low" verbal interpretation category. This indicates relatively poor performance and suggests that students held significant misconceptions and demonstrated limited conceptual understanding of heat and temperature. The low scores highlight the shortcomings of traditional teaching methods in addressing and correcting students' preconceived notions and emphasize the need for instructional strategies that prioritize conceptual clarity over rote memorization. These findings establish a clear baseline, justifying the implementation of targeted, concept-focused educational interventions.

In the posttest, the results indicate a Mean Percentage Score (MPS) of 87.18% (M = 17.438, SD = 1.865), which corresponds to a "High" verbal interpretation. The substantial increase reflects a significant improvement in conceptual understanding and a notable reduction in misconceptions. These outcomes validate the effectiveness of the intervention, particularly the VR Integrated Guided Inquiry Based Pedagogy, and underscore the importance of engaging, student-centered approaches. Strategies grounded in constructivist principles, which build on learners' prior knowledge, play a crucial role in promoting accurate scientific understanding. Overall, the data in Table 5 illustrate a marked improvement in students' understanding of heat and temperature, affirming the critical role of innovative, conceptually driven teaching strategies in developing scientific literacy, which is a foundational goal of science education.

Table 5**.** Wilcoxon Signed-Rank Test for the Difference Between the Students' Pretest and and Posttest on the Misconception and Conceptual Understanding on Heat and Temperature

Skills Developed	**Pre-test**	**SD**	**Post test**	**SD**	**z**	**Asymp. Sig**	**r**	**Verbal Interpretation**
Conceptual Understanding	5.625	1.879	17.438	1.865	4.946	0.000*	O.618	Large effect

Note: significant at α = 0.05; at No. of Items =20, effect size (Cohen's d) is (r=z/√2N), 0.10>r<0.30 (small effect), 0.50<r>0.30 (medium effect), and r>0.50 (large effect).*

Table 5 presents the results of the Wilcoxon Signed-Rank Test, which was conducted to determine whether there was a statistically significant difference in students' conceptual understanding of heat and temperature before and after the instructional intervention. The test was selected as a non-parametric alternative to the paired-samples t-test, given the possibility that the data did not meet the assumption of normality. It is particularly suitable for analyzing repeated measures from the same participants, such as the pretest and posttest scores in this study.

The results revealed a substantial and statistically significant improvement in student performance following the intervention. Specifically, the mean score on the pretest was relatively low (M = 5.625, SD = 1.879), indicating limited prior understanding and the likely presence of misconceptions related to heat and temperature concepts. After the intervention, the posttest scores showed a marked improvement (M = 17.438, SD = 1.865), reflecting significant gains in students' conceptual understanding. The Wilcoxon Signed-Rank Test yielded a z-value of 4.946 with an associated p-value of 0.000. Since the p-value is well below the conventional alpha level of 0.05, the results indicate that the observed increase in scores from pretest to posttest is statistically significant and unlikely to have occurred by chance.

In addition to statistical significance, the magnitude of the effect was assessed through the calculation of the effect size. The effect size, computed as $r = 0.618$, is interpreted as a large effect based on Cohen's (1988) criteria. This means that the intervention not only led to statistically significant gains but also had a strong practical impact on students' learning outcomes. The large effect size demonstrates that the instructional approach was highly effective in producing meaningful improvements in conceptual understanding. The findings presented in Table 5 have important implications for science education, particularly in areas that are prone to misconceptions, such as heat and temperature. The significant increase in posttest scores, coupled with the large effect size, indicates that the instructional intervention successfully addressed and corrected students' misconceptions. It also supports the use of targeted teaching strategies such as concept-based instruction, inquiry-based learning, and formative assessment to promote deeper understanding of scientific concepts. These results underscore the potential of well-designed instructional approaches to bring about conceptual change and meaningful learning in science classrooms. Overall, the data presented in Table 5 provide strong evidence that the intervention was effective in enhancing students' conceptual understanding of heat and temperature. The statistically significant improvement in scores ($M = 5.625$, $SD = 1.879$ to $M = 17.438$, $SD = 1.865$), along with the large effect size ($r = 0.618$), highlights the success of the intervention in achieving its educational objectives and offers valuable insights for future instructional planning and curriculum development.

Qualitative Findings

Thematic Analysis of Responses on Reflective Questionnaire

To assess their perceptions of using the VR Science Simulation, students reflected on their learning experiences through the questionnaire. From their responses, three underlying themes emerged: *Instructional Impact through Technology, Pedagogical Effectiveness,* and *Learning Difficulties.*

As shown in Table 6, the thematic analysis of student reflections underscores the significant instructional and pedagogical value of the VR Science Simulation. A prominent theme was enhanced conceptual understanding, with students reporting clearer insights into abstract topics like heat transfer and molecular behavior. Additionally, students noted improvements in visualization of lessons, stating that VR allowed them to "see" how molecules behave at different temperatures. The simulation's pedagogical effectiveness was also evident in students' descriptions of experiential learning, where the VR environment made them feel as though they were inside a laboratory.

Moreover, student engagement increased, as indicated by their enjoyment and interest during the simulations. Despite these benefits, the study also surfaced important challenges, including physical discomfort (e.g., eye strain, dizziness). Likewise, technical and accessibility issues such as poor internet connectivity and device limitations emphasizing the infrastructural demands of implementing VR in classroom settings. Overall, the qualitative data affirm that VR-based instruction can meaningfully improve science learning by enhancing comprehension, engagement, and motivation. However, the findings also highlight the need to address ergonomic design and technical accessibility to ensure equitable and sustainable use in educational contexts.

Table 6. Summary of Thematic Analysis of Student Reflections on VR Science Simulation

Main Theme	Sub-Themes	Key Ideas / Codes	Frequency
Instructional Impact through Technology	Enhanced Knowledge	Understood concepts better, learned new ideas, grasped molecular motion	20
	Visualization of Lesson	Imagined real-life scenarios, saw molecular behavior in different temperatures	7
	Immersive Learning Experience	Explored simulation, found learning fun and engaging	3
Pedagogical Effectiveness	Engaging Learning	Maintained interest and attention during VR simulations	2
	Experiential Learning	Felt like being in a laboratory, experienced content through 360° immersive views	21
	Conceptual Understanding	Differentiated between heat and temperature, improved clarity of concepts	3
Difficulties Encountered	Physical Discomfort	Eye strain, dizziness, sensitivity from prolonged use of VR	22
	Technical & Accessibility Issues	Internet lag, device incompatibility, performance issues	11

Conclusion

This study investigated the effectiveness of a VR-integrated Guided Inquiry-Based Approach (GIBA) in enhancing Grade 7 students' conceptual understanding of heat and temperature. The findings revealed that students held prevalent misconceptions—such as equating heat with temperature or misunderstanding thermal energy transfer—which hindered their comprehension of fundamental physics concepts. Through the implementation of the VR-enhanced module, students demonstrated significant improvements in conceptual understanding, as evidenced by higher post-test scores and decreased misconceptions. The immersive nature of the virtual environment enabled students to visualize abstract processes, manipulate variables, and engage actively in inquiry, all of which contributed to deeper learning. Furthermore, thematic analysis of students' reflections underscored their increased motivation, curiosity, and engagement during the intervention. These results affirm that combining VR with guided inquiry holds considerable promise in making science instruction more effective, meaningful, and responsive to students' learning needs. The study highlights the potential of innovative pedagogies grounded in constructivist learning theories to transform science education and bridge persistent conceptual gaps.

Recommendations

In light of the study's findings, it is recommended that VR-integrated guided inquiry-based strategies be strategically expanded within science curricula, particularly for abstract and misconception-prone topics such as heat and temperature, energy transfer, forces, and electricity. The demonstrated gains in conceptual understanding and experiential learning highlight VR's capacity to make invisible scientific processes tangible and inquiry-driven. However, integration should be pedagogically purposeful rather than technology-driven, ensuring that VR activities are embedded within well-structured inquiry phases (exploration, explanation, and reflection).

Given the reported physical discomfort (e.g., eye strain and dizziness), educators are advised to limit VR exposure time, incorporate regular breaks, and adopt age-appropriate ergonomic guidelines when implementing immersive simulations. Blended instructional designs—combining short VR sessions with discussion, hands-on tasks, and reflective activities—may help maximize learning benefits while safeguarding student well-being. Teacher training programs should therefore emphasize not only technical proficiency but also health-conscious instructional design and classroom management strategies for immersive technologies.

To address technical and accessibility challenges, school administrators and policymakers are encouraged to invest in reliable digital infrastructure, including compatible devices and stable internet connectivity. For under-resourced schools, the adoption of low-cost, mobile-based, or offline VR solutions should be explored to promote equitable access. Partnerships with educational technology providers and local institutions may further support sustainable implementation.

Additionally, the regular use of reflective and metacognitive tools, such as the Student Reflective Questionnaire (SRQ), is recommended to help learners articulate their experiences, monitor conceptual growth, and surface persistent misconceptions. Embedding reflection within VR-enhanced inquiry can strengthen conceptual consolidation and self-regulated learning.

Future research should examine the long-term effects of VR-integrated inquiry on knowledge retention, transfer, and higher-order thinking skills, as well as its applicability across diverse science domains and learner populations. Comparative and longitudinal studies across grade levels and contexts are particularly encouraged. Finally, the co-development of VR learning materials involving teachers, students, curriculum experts, and technologists is essential to ensure contextual relevance, curricular alignment, and pedagogical effectiveness within local educational settings.

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