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**To cite this article:**

Parong, M.K., Estrella, J.P., Magat, M., Resurreccion, A.J., Miranda, M., & Antonio, R. (2025). Fostering junior high school students' conceptual understanding of Charles' Law using Contextualized-Interdisciplinary-Based Module. *International Journal on Engineering, Science, and Technology (IJonEST),* *7*(1), 49-82. https://doi.org/10.46328/ijonest.5280

IJONEST
International Journal on Engineering, Science, and Technology
2025, Vol. 7, No. 1, 49-82 https://doi.org/10.46328/ijonest.5280

# Fostering Junior High School Students' Conceptual Understanding of Charles' Law Using Contextualized-Interdisciplinary-Based Module

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**Article Info**

***Article History***

Received:
2 March 2025
Accepted:
9 June 2025

***Keywords***

Charles' Law
Climate change
Contextualized-Interdisciplinary approach
Contextualized-Interdisciplinary-Based Module (CIBM)
Environmental education
Science pedagogy

**Abstract**

As climate change continues to intensify, the need for scientifically literate and environmentally conscious learners becomes increasingly urgent. This study developed and implemented a Contextualized-Interdisciplinary-Based Module (CIBM) on Charles' Law, grounded in a Contextualized-Interdisciplinary Approach (CIA) that integrates chemistry, atmospheric science, environmental issues, and technology. Designed for Grade 10 students in the Philippines, the module aimed to enhance conceptual understanding by linking gas laws to real-world phenomena such as the greenhouse effect and rising global temperatures. Using a pre-experimental design, the study combined expert validation, a pretest-posttest of conceptual understanding, and thematic analysis of student reflections. Results revealed that students initially demonstrated only near-proficiency in conceptualizing the volume–temperature relationship and its environmental applications. Following exposure to the module, students showed significant improvement, with posttest scores reaching high proficiency levels and a large effect size ($r = 0.85$) confirmed through the Wilcoxon signed-rank test. Qualitative findings further indicated increased engagement, deeper comprehension, and stronger real-world connections, particularly in understanding climate change. The module was also positively evaluated by experts in terms of content accuracy, instructional design, language, and digital integration. These findings highlight the value of contextualized, interdisciplinary, and technology-supported pedagogy in making abstract scientific concepts more tangible, meaningful, and socially relevant. This study underscores the potential of such approaches to advance not only academic outcomes in science education but also critical awareness and preparedness to address global environmental challenges.

## Introduction

The world is undergoing rapid environmental transformation, with climate change emerging as one of the most pressing global challenges of the 21st century. Despite its profound and escalating impact on ecosystems, economies, and human well-being, climate science remains underrepresented in many educational settings, particularly in science instruction where foundational concepts, such as *Charles' Law*, are frequently taught in isolation, devoid of real-world context or interdisciplinary connections. This disconnects between scientific theory and real-world application can hinder students' conceptual understanding. Charles' Law, which describes the direct relationship between the volume and temperature of a gas, is a critical concept in thermodynamics and atmospheric science. Its principles underlie phenomena such as thermal expansion and the behavior of greenhouse gases, processes essential to understanding climate change. Yet, students often struggle to grasp these abstract ideas when instruction is limited to mathematical formulations without meaningful, contextual grounding (Kikas & Hillar, 2019; Lin et al., 2024).

In response to this pedagogical gap, interdisciplinary and context-based teaching approaches have gained traction as effective strategies for enhancing student engagement and comprehension. This study draws upon a *Contextualized-Interdisciplinary Approach (CIA*) to bridge the gap between theoretical science and global environmental issues. By embedding climate-related phenomena into chemistry instruction, the approach situates learning within authentic and relevant contexts, helping students relate abstract gas laws to their lived experiences. Central to this study is the development and implementation of a *Contextualized-Interdisciplinary-Based Module (CIBM)* focused on Charles' Law. The module integrates concepts from atmospheric science with interactive digital tools, notably *PhET Interactive Simulations*, to visualize gas behavior dynamically. Such technologies have been shown to enhance learning outcomes by making abstract concepts more concrete, increasing student motivation, and supporting inquiry-based learning (Acenas et al., 2019; Herga et al., 2020).

In the Philippine context, where climate change is experienced through intensifying typhoons, flooding, and sea-level rise, incorporating climate literacy into science curricula is particularly urgent. As emphasized by PAGASA (2023), a scientifically informed citizenry is essential to building climate resilience. By connecting Charles' Law to climate-related phenomena familiar to Filipino students, the CIBM approach not only deepens conceptual understanding but also cultivates environmental awareness and critical thinking. Previous studies, by Torres and Villanueva (2020) showed positive outcomes in which students in the interdisciplinary approach demonstrated high levels of engagement, improved understanding of scientific principles, and better ability to apply knowledge to real-world issues. The use of technology in education, such as virtual laboratories, simulations, and interactive models, proved effective in increasing students' conceptual understanding of complex scientific laws.

Moreover, this pedagogical innovation aligns with global education imperatives, notably the *United Nations Sustainable Development Goals (SDGs*). Specifically, it supports *SDG 4 (Quality Education*), which advocates for inclusive, equitable, and meaningful learning opportunities, and *SDG 13 (Climate Action*), which underscores the importance of education in addressing climate change. Thus, the integration of contextualized and interdisciplinary learning, supported by digital tools, presents a strategic pathway to equip students with both scientific literacy and environmental consciousness.

**Research Questions**

This study investigated the effectiveness of a Contextualized-Interdisciplinary Approach (CIA) in promoting students' conceptual understanding of gas laws, specifically Charles' Law, which explained the rising temperatures due to climate change. Specifically, the study aimed to address the following questions:

1. How may the Contextualized-Interdisciplinary-based Module (CIBM) on Charles' Law anchored on Contextualized-Interdisciplinary Approach (CIA) be developed and assessed in terms of:
    1.1 content validity;
    1.2 instructional design and organization;
    1.3 assessment and evaluation;
    1.4 format, and;
    1.5 language;
2. How may the students' conceptual understanding of Charles' Law be described before and after exposure to the Contextualized-Interdisciplinary Approach (CIA)?
3. Is there a significant change in conceptual understanding before and after the Contextualized-Interdisciplinary Approach (CIA)?
4. What are the students' perceptions, insights, and experiences regarding the Contextualized-Interdisciplinary Approach (CIA)?

## Literature Review

### Interdisciplinary Approach in Science Education

The theoretical foundation of this study is further supported by related literature emphasizing interdisciplinary approaches in science education. You (2017) argues that science learning is most effective when disciplines are integrated, reflecting the interconnected nature of real-world phenomena. Sharma and Shukla (2023) similarly note that interdisciplinary learning enhances practical understanding and prepares students to address complex problems. Newell (1998) adds that interdisciplinary instruction cultivates higher order thinking skills such as critical and synthetic reasoning, reinforcing the pedagogical value of integrating chemistry with climate science.

### Climate Change Education in Chemistry

In climate change education within chemistry, Mahaffy et al. (2024) highlight the importance of interactive, resource-rich approaches that connect chemistry concepts to climate literacy and action. Igboanugo and Naiho (2024) emphasize the role of chemistry education in promoting climate change mitigation behaviors, while Versprille et al. (2017) demonstrate that climate-related examples effectively support learning of gas behavior and electromagnetic radiation when students' prior knowledge is considered.

### Students' Conceptual Understanding in Chemistry

Research on students' conceptual understanding in chemistry further underscores the need for effective strategies. Andayani et al. (2018) found that negative perceptions, conceptual difficulty, and weak numerical reasoning hinder learning, while Dela Cruz et al. (2024) showed that structured inquiry-based learning significantly improves conceptual understanding. Sawyer (2008) emphasizes that true understanding occurs when students can apply knowledge to real-life contexts. Anderson et al. (2017) identify persistent misconceptions about climate-related chemical processes and recommend integrating climate change into chemistry curricula to address these gaps.

### Technology Integration in Teaching Chemistry

Studies on technology integration in chemistry education support the use of simulations and virtual laboratories. Belford and Gupta (2019) highlight the value of technological resources in enhancing instruction and learning. Correia et al. (2019) and Chiu et al. (2015) demonstrate that PhET simulations and augmented virtual laboratories significantly improve students' understanding of gas behavior at molecular, macroscopic, and symbolic levels, while also promoting positive learning experiences.

## Theoretical Framework

This study is anchored on a coherent set of learning theories and empirical literature that collectively emphasize student-centered, context-rich, and cognitively supported science instruction. These frameworks justify the integration of climate change contexts in teaching Charles' Law and support the use of interdisciplinary and technology-enhanced approaches to improve students' conceptual understanding.

### Constructivist Learning Theory

At the core of this framework is Constructivist Learning Theory, which emphasizes that learners actively construct knowledge by making sense of their experiences (Olusegun, 2015). Rather than passively receiving information, students build understanding based on prior knowledge and personal interpretation. Hein (2002) further explains that while teachers organize and present knowledge about the real world, learning occurs as students actively engage with and rationally structure this information. Applying climate change concepts to Charles' Law aligns with constructivist principles by situating abstract gas laws within meaningful, real-world phenomena, enabling students to take ownership of their learning and develop deeper conceptual understanding.

### Context-Based Learning Theory

Extending constructivism, Context-Based Learning Theory (CBLT) highlights the importance of embedding scientific content within relevant, real-life contexts. Bennett et al. (2007) emphasize that context-based learning fosters emotional engagement by helping students recognize the value and relevance of science in addressing real-world issues. Similarly, Bennett (2003) notes that CBLT enables students to see science as an interconnected and dynamic discipline rather than a collection of isolated facts. Osborne and Dillon (2008) further argue that this approach is particularly effective for students who perceive science as disconnected from their lives or future careers. By contextualizing Charles' Law within climate change, this study strengthens relevance, motivation, and conceptual engagement, complementing constructivist goals.

**Experiential Learning Theory**

Experiential Learning Theory (ELT), proposed by Kolb (1984), adds an action-oriented dimension by emphasizing learning through direct experience. ELT follows a four-stage cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Lai et al. (2007) demonstrate that technology-enhanced simulations effectively support this cycle by allowing learners to test ideas, reflect on outcomes, and apply concepts in dynamic environments. Similarly, DeKorver and Towns (2022) found that hands-on, student-designed experiments significantly improve practical skills and scientific understanding. In this study, simulations and climate-based scenarios allow students to experience gas behavior firsthand, reinforcing conceptual understanding of Charles' Law while aligning with real-world environmental contexts.

**Situated Learning Theory**

Complementing ELT, Situated Learning Theory (SLT) emphasizes learning in authentic and socially meaningful contexts. Lave and Wenger (1991) argue that knowledge is constructed through participation in communities of practice, where learners gradually progress from novices to experts. Research by Brown et al. (1989) and Collins et al. (1989) shows that authentic tasks enhance conceptual understanding and critical thinking by linking theory to practice. Greeno (1997) and Herrington and Oliver (2000) further highlight the role of technology and innovative pedagogy in making abstract concepts more accessible. By integrating climate change scenarios and digital simulations, this study situates learning in contexts that mirror real-world problem-solving, consistent with SLT principles. In teacher education, Borko (2004) underscores the value of situated professional learning, enabling educators to contextualize scientific principles effectively within their instructional practices.

**Conceptual Change Theory**

While these theories emphasize engagement and context, Conceptual Change Theory (CCT) addresses the challenge of students' misconceptions in science learning. Gilbert et al. (1982) emphasize that prior knowledge actively shapes how students interpret new information, often leading to conflicts with scientific explanations. Mayer (2000) describes conceptual change as accommodative learning, where students restructure existing cognitive frameworks to integrate new and sometimes contradictory information. In the context of climate change and gas laws, students often hold misconceptions that hinder understanding. By presenting scientifically accurate representations of Charles' Law within environmental contexts, this study facilitates cognitive restructuring and promotes deeper conceptual change.

**Cognitive Load Theory**

To support these learning processes, Cognitive Load Theory (CLT) provides guidance on managing the cognitive demands of complex, interdisciplinary instruction. Sweller (1988) explains that working memory has limited capacity, making instructional design critical. Chandler and Sweller (1991) and Clark et al. (2006) highlight the effectiveness of worked examples in supporting schema formation. Bannert (2002) identifies three types of cognitive load: intrinsic, extraneous, and germane. Teaching Charles' Law alongside climate change presents high intrinsic load due to the complexity of both chemistry and environmental science. This study manages intrinsic load by using simulations to break down abstract concepts into manageable representations. Extraneous load is minimized through well-designed, user-friendly tools such as PhET simulations, while germane load is fostered by encouraging students to actively connect new concepts with prior knowledge. CLT thus provides the cognitive structure that integrates and supports constructivist, context-based, experiential, and situated learning approaches.

## Method

### Research Design

This study employed a developmental research design that integrated both qualitative and quantitative approaches. This design was selected to address the two primary objectives of the study: the development and validation of a Contextualized-Interdisciplinary-Based Module (CIBM) on Charles' Law, and the assessment of its effectiveness in improving students' conceptual understanding. Quantitative methods were utilized through (a) validation of the learning module's content, technology integration, and language, and (b) a pre-experimental pre-test and post-test to measure changes in student understanding before and after exposure to the CIBM. This approach enabled the researchers to measure changes in student performance before and after the intervention without requiring randomized assignment, which was not feasible in the natural school setting. The use of pre-intervention and post-intervention assessments allowed for the identification of any significant improvement in students' understanding of Charles' Law because of the instructional material.

Meanwhile, the Qualitative methods complemented the quantitative data by capturing students' reflections and perspectives. Open-ended questions included in both the pretest and posttest explored the learners' initial and final views on how Charles' Law explains the science behind the greenhouse gas effect and its connection to rising temperatures. Further qualitative data were gathered through a Student Perception Questionnaire (SPQ), which examined students' experiences, perceptions, and insights about the implementation of the CIA as an instructional method. Responses were analyzed through thematic analysis, allowing researchers to generate codes and extract themes that illustrated the impact of the intervention on students' understanding and engagement. This combination of methods provided a comprehensive evaluation of the intervention. The mixed-methods design allowed the researchers to assess both measurable learning gains and the broader learning experiences of students, ensuring a more holistic understanding of the impact of the Contextualized-Interdisciplinary Approach.

### Research Locale and Participants

The participants of this study involved one section of Grade 10 students enrolled in a public high school in Marilao, Bulacan, Philippines, during the Academic Year 2024–2025. The school was selected based on criteria including availability, accessibility, geographical proximity, and its relevance to the study's environmental context. The location was appropriate due to its exposure to climate-related challenges, particularly elevated heat index levels and seasonal flooding, which made it a suitable setting for applying Charles' Law to real-world situations.

A total of twenty-five (25) students participated in the study, intentionally chosen through purposive sampling to provide meaningful perspectives relevant to the intervention. This non-probability sampling approach, as outlined by Tongco (2007), was widely recognized in both quantitative and qualitative research for its emphasis on selecting participants who could offer valuable contributions, rather than relying on random selection. Throughout the study, all selected participants engaged fully as they completed the pretest, worked through the Contextualized-Interdisciplinary-Based Module (CIBM), and completed the posttest, helping ensure the smooth and effective implementation of the intervention. Based on demographic data, eighteen participants identified as female (72%), six as male (24%), and one as part of the LGBTQIA+ community (4%). In terms of age, sixteen students were fifteen years old (64%), eight were sixteen (32%), and one student was eighteen years old (4%).

**Research Instruments**

***Adapted Content Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law***

The quality of the Contextualized-Interdisciplinary-based Module (CIBM) was assessed based on the adapted criteria outlined in the DepEd Evaluation Rating Scales and their alignment with the Contextualized-Interdisciplinary Approach (CIA). The researchers adapted the *DepEd's Learning Resources Management System (LRMDS) evaluation*. This instrument was designed to guide the development and validation of the Contextualized-Interdisciplinary-based Module (CIBM) aligned with the research's objectives. The tool was divided into four (4) main categories: content, instructional design and organization, format, and language. The table below presents the standards and indicators that were considered in the development and validation of the learning module on the topic of Charles' Law.

Table 1. Adapted Content Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law

| Component | Sample Statement |
|---|---|
| Factor 1: Content | |
| Alignment with Curriculum Standards | • The module is aligned with the DepEd K-12 Science Curriculum Guide for Grade 10 Science.<br>• The learning competencies on Charles' Law and its real-life applications are explicitly addressed. |
| Contextualization | • Examples are related to global warming and its effects on gas behavior.<br>• The module incorporated interdisciplinary links (e.g., Mathematics and Technology). |
| Accuracy and Relevance | • The explanations of Charles' Law are linked to observable environmental phenomena. |
| Factor 2: Instructional Design and Organization | |
| Engagement and Motivation | • The activities have the potential to arouse the interest of the target |

| Component | Sample Statement |
|---|---|
| | readers. |
| Logical Flow | • The lessons are organized logically, progressing from basic concepts of gas laws to the application of Charles' Law. |
| Differentiation and Inclusivity | • The varied tasks cater to different styles of learners. |
| Factor 3: Assessment and Evaluation | |
| Assessment | • The assessments are aligned with the lesson objectives and content. |
| Rubrics and Criteria | • The rubrics provided for each activity were aligned to the module's objective. |

***Adapted Technology-Integration Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law***

The researchers utilized the Adapted Technology-Integration Evaluation Rating Sheet of CIBM as a key instrument in assessing the suitability and effectiveness of the technological tools integrated into the learning module they developed. This evaluation ensured that the selected tools aligned with educational objectives, enhanced the learning experience, and met the necessary standards. Additionally, this instrument served as a guiding framework in constructing the learning module, shaping its structure, instructional strategies, and overall design to optimize its impact on learners.

Table 2. Adapted Technology-Integration Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law

| Components and Sample Statements |
|---|
| Factor 1: Content |
| • The module effectively integrates technology to enhance student engagement.<br>• The use of technology aligns with best practices in digital learning. |
| Factor 2: Interactivity and Engagement |
| • The module includes interactive elements (e.g., simulations) |
| Factor 3: Accessibility and Usability |
| • The digital content is user-friendly and promotes an intuitive learning experience.<br>• The module promotes 21st-century learning skills. |
| Factor 4: Quality of Digital Content |
| • The visual and multimedia elements enhance learning.<br>• The digital tools and resources used are up-to-date and relevant to science education. |

Table 2 shows the Adapter Technology-Integration Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM), wherein categories included in this tool are the integration of technology in learning, interactivity and engagement, accessibility and usability, and quality of digital content.

The researchers opted to modify the original Technology-Integration Evaluation Rating Sheet by removing some categories to better align the instrument with the specific context and instructional objectives of the CIBM. This decision was guided by the principle of contextual adaptation in instructional design, which emphasizes the need to adjust tools to the local learning environment and target users. Nur'ainy and Sujarwo (2025) similarly demonstrated this approach in their development of a digital module for vocational schools, where components were selectively included based on learner needs, expert feedback, and practical considerations. Their use of the ADDIE model highlights the value of ongoing refinement and the flexibility to omit elements that do not contribute meaningfully to module effectiveness. By following this model, the researchers ensured that the adapted evaluation tool remained valid, focused, and relevant to the goals of science education within the specific setting of the CIBM.

***Adapted Language Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law***

The Adapted Language Evaluation Rating Sheet was used to validate the language and grammar of the learning module developed by the researchers. This instrument guided the researchers in constructing the learning module. The tool is divided into two (2) standards: Format and Language. The researchers modified the instrument from the content evaluation rating sheet to specify the criterion items that were considered in the development and validation of the learning module.

Table 3. Adapted Language Evaluation Rating Sheet of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law

| Components | Sample Statement |
|---|---|
| Factor 1: Format | |
| Text | • Size of letter is appropriate to the intended user.<br>• Space between letters and words facilitate reading. |
| Illustrations | • Simple and easily recognizable.<br>• Properly labeled or captioned. |
| Design and Layout | • Attractive and pleasing to look at. |
| Factor 2: Language | |
| Clarity of Language | • The language used is learner-friendly and age-appropriate.<br>• Transition devices consistently emphasize key topics and signal shifts between ideas. |

***Conceptual Understanding Test on Charles' Law (CUTCL)***

The researchers adapted and modified a Conceptual Understanding Test on Charles' Law on the Grade 10 learning materials in Quarter 4 Module 2. It was validated by ten (10) experts in science and one (1) language expert. This assessment functions as a pretest and posttest that gauges the progress made in conceptual comprehension of students before and after being exposed to the CIBM. The CUTCL pretest was administered before discussing

Charles' Law. On the other hand, the posttest was given after the students completed the days of discussion and answered the learning module.

Both pretest and posttest consisted of 20 multiple-choice questions with four choices each and a 2-item essay with one open-ended question each that underscore the interdisciplinary links of Charles' Law to climate change. A maximum of 30 points would be allocated for this, as each correct answer in the 20-point multiple choice question is equivalent to one (1) point, while the answers of the students in the essay part would be graded through the provided rubrics with a maximum score of 5 points for each question.

Table 4. Table of Specification of Conceptual Understanding Test on Charles' Law for Pretest and Posttest

| Learning Objectives | Item No. | | Sample Questions |
|---|---|---|---|
| | Pretest | Posttest | |
| LO 1. | 14 | 13 | 14. Jacques Alexandre Charles performed an experiment using a balloon, hot water, and cold water. Which of the following statements is proposed in Charles' Law?<br>A. The Kelvin temperature and the volume of a gas are directly related to constant pressure.<br>B. The volume of a given mass of gas held at constant temperature is inversely proportional to its pressure.<br>C. The pressure of a fixed amount of a gas is directly proportional to the absolute temperature (Kelvin).<br>D. The volume of a gas varies directly with the number of moles and absolute temperature and inversely proportional with pressure. |
| LO 2. | 8 | 7 | 8. Theoretically, how might increasing temperature of the atmosphere relate to Charles' Law?<br>A. As temperature rises, volume increases in the atmosphere.<br>B. As temperature rises, the volume decreases in the atmosphere.<br>C. Temperature and volume are not connected in the atmosphere.<br>D. Temperature does not affect the volume of air in the atmosphere. |
| LO 3. | 21 | 22 | 21. Considering Charles' Law states that gases expand when heater, how might increasing global temperature affect the behaviors of greenhouse gases and contribute to climate change. |

Table 4 represents the Table of Specification (TOS) of CUTCL, in which there are three learning objectives, namely, Learning Objective 1, which aims to explain the relationship of volume and temperature of greenhouse gases at constant pressure; Learning Objective 2, which involves investigating how the reaction of greenhouse gases to increasing atmospheric temperature contributes to the greenhouse effect and subsequent climate change using virtual simulation; and Learning Objective 3, which tasks students to write reflection on Charles' Law principles and its application to the greenhouse effect and climate change.

***Students' Perception Questionnaire (SPQ)***

Following the teaching intervention, students completed the Student Perception Questionnaire (SPQ). The SPQ consists of five open-ended questions that encourage students to share their thoughts and describe their overall learning experience with this approach. The questions included in the SPQ are as follows:

1. How does the Contextualized-Interdisciplinary Approach help you learn Charles' Law?
2. How do you feel about using real-world issues like climate change to learn Charles' Law?
3. Were there any challenges you encountered during the lesson? If yes, please describe them.
4. How did incorporating experiments or activities into the lesson help you understand Charles' Law better?
5. What suggestions do you have to improve the use of real-world issues in teaching Charles' Law?

**Research Procedures**

The research employed the ADDIE model of instructional design, which included the stages of analysis, design, development, implementation, and evaluation. By integrating the ADDIE model and its core components and principles into teaching practices, educators can develop engaging and effective learning experiences for students (Adeoye et al., 2024). Following the study, Figure 1 presents an image illustrating the steps involved in conducting this research using the ADDIE model.

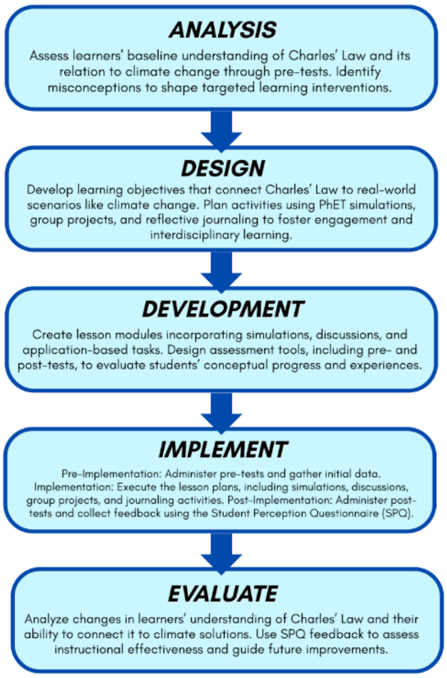


Figure 1. Research Procedures Based on the ADDIE Model

***Analysis Phase***

The problem scenario, research objectives, and lesson scope were determined, forming the foundation for the intervention's content. Before developing the learning exemplars for the CIA, the researchers analyzed the characteristics of learners with the lowest mastery of Charles' Law.

***Design Phase***

Specific learning and instructional objectives were made based on the problem scenario. These objectives were aligned with the identified least mastered competency in science among grade 10 learners in the 4th quarter: *investigate the relationship between volume and temperature at constant pressure of a gas, S10MT-IVa-b-21.* The researchers used these objectives as their guide in crafting the learning module content.

***Development Phase***

The developmental phase is divided into three subphases: the (1) crafting lesson plans and modules, (2) developing interdisciplinary activities, and (3) designing pretest and post-test tools to measure learners' conceptual understanding. The researchers first developed lesson exemplars that included lesson plans and modules. These learning exemplars incorporated the context of climate change into Charles' Law. After developing the learning exemplars, the researchers planned activities such as simulations, experiments, and problem-solving tasks that helped learners understand Charles' Law. Following the first two stages, the learning exemplars were validated during the validation phase through the adopted Department of Education's Learning Resources Management System (LRMDS) evaluation. Lastly, the third stage underscored the designing of pretest and posttest tools to assess learners' conceptual understanding of Charles' Law before and after exposure to the Contextualized-Interdisciplinary Approach (CIA).

***Implementation Phase***

The *pre-implementation phase* which focused on securing necessary permissions and preparing participants. The researchers first obtained formal approval from the Department of Education (DepEd) and the school principal. Once permission was granted, assent forms and parental consent letters were distributed to the participating Grade 10 students. After securing consent, the researchers conducted an orientation session to explain the study's objectives, the role of the module, ethical considerations, and the procedures involved. Following this, the students took the Conceptual Understanding Test on Charles' Law (CUTCL) as a pretest. This instrument, consisting of 20 multiple-choice questions and 2 open-ended essay items, was designed to assess their baseline knowledge of Charles' Law and its relevance to climate-related scenarios.

The *implementation phase* involved the delivery of the Contextualized-Interdisciplinary-Based Module (CIBM) using the Contextualized-Interdisciplinary Approach (CIA). The lessons were facilitated by the researchers and incorporated interdisciplinary content from chemistry, atmospheric science, and environmental issues. Students explored the relationship between gas laws and real-world climate phenomena through contextualized tasks, teacher-guided discussions, and interactive simulations. A key feature of this phase was the integration of PhET Interactive Simulations, which allowed students to manipulate variables and visualize the behavior of gases under different temperature conditions. These activities supported deeper understanding by linking abstract scientific concepts to everyday environmental issues.

The *post-implementation phase* focused on evaluating the outcomes of the intervention. After completing all module activities, students were given the CUTCL again as a posttest, allowing the researchers to assess changes in their conceptual understanding. The same structure and scoring rubrics were used to ensure comparability with the pretest results. In addition to the posttest, students answered the Student Perception Questionnaire (SPQ), which gathered qualitative data on their experiences, insights, and challenges throughout the intervention. This stage provided a comprehensive view of both the cognitive and affective impacts of the module, capturing how the interdisciplinary and contextualized approach influenced learning.

Table 5. Instructional Flow for Teaching Charles' Law According to the CIBM

| Phase | Activity Description | Key Components |
|---|---|---|
| *Pre-Implementation* | Administered a pretest to assess students' baseline knowledge of Charles' Law and its relation to climate change. | Pre-assessment tools and identification of misconception. |
| *Elicit*<br>Activating Prior Knowledge & Reviewing Previous Topic | Encouraged students to critically think about gas behavior in real-world climate context. | Students were given a prompt to answer that was related to how Charles' Law explains climate change, and tasked to observe how Charles' Law govern the science behind the gas behavior in baking *pandesal*. |
| *Engage*<br>Motivation | Introduced the GHGs and the greenhouse gas effect and its role in climate change. | Authentic and relevant context; connect to global context. |
| *Explore*<br>Hands-on Investigation and Data Collection | Engaged students with PhET Simulations to observe gas behaviors under varying temperature and pressure conditions. | Use of multi-modal resources; interactive and inquiry-based learning. |
| *Explain*<br>Introduction of Scientific Concepts | - Assigned activities where students conducted experiments demonstrating Charles' Law in climate scenarios.<br>- Facilitate discussions linking Charles' Law to GHG effects and thermal expansion. | - Analyze the results from the simulation and balloon experiment.<br>-Thematic and interdisciplinary integration; scaffolding and differentiation. |
| *Elaborate*<br>Apply the Concept in Real-World Context | Students relate the volume-temperature changes to climate change impacts. | Integration of 21st-century skills; hands-on experience. |
| *Evaluate*<br>Assess Learning Understanding | Administered a short quiz that assesses the understanding of students on how Charles' Law | Matching Type Short Quiz |

| Phase | Activity Description | Key Components |
|---|---|---|
| | explains the subsequent climate change. | |
| *Extend* Encourage Further Application | Guide students in reflective journaling about their learning process and how Charles' Law connects to solving climate change. | Reflection and metacognition; focus on deeper understanding. |
| *Post-Implementation* | Administered a posttest and gathered students' feedback using the SPQ | Formative and summative assessment; thematic analysis of quantitative data. |

This Contextualized-Interdisciplinary Approach (CIA) intervention provided students with the tools to understand and apply Charles' Law in meaningful, real-world contexts, specifically focusing on climate change and environmental issues. By combining interdisciplinary learning, hands-on simulations, and project-based assessments, this teaching intervention aims to foster a deeper understanding of scientific principles, enhance students' problem-solving skills, and promote environmental responsibility. Through this approach, students will not only learn chemistry but also gain critical thinking skills that are essential for addressing the complex challenges of the modern world.

***Evaluation Phase***

The Evaluation phase measured the significant changes in the conceptual understanding of the learners following their exposure to the Contextualized-Interdisciplinary Approach (CIA). The administration of the Students' Perception Questionnaire (SPQ) was used to further explore the participants' experiences, perceptions, and insights after their exposure to the CIA.

**Data Analysis**

The study combined quantitative and qualitative research methodologies to assess whether significant changes occur in students' conceptual understanding after participating in the Contextualized-Interdisciplinary Approach (CIA). Quantitative data analysis involved identifying the mean and standard deviation of the data gathered from the validation of the intervention. It also included the calculation of the mean, standard deviation, and mean percentage scores to assess students' conceptual understanding of the topic, based on their pretest and posttest results from the Conceptual Understanding Test in Gas Laws: Charles' Law. These procedures fall under descriptive statistics, which are essential for summarizing data in an organized manner and represent a vital first step in research before conducting inferential analysis (Kaur et al., 2018).

The same group of students was assessed at two time points, before and after the intervention. However, the data did not meet the assumptions of normality, as the pretest and posttest scores were not normally distributed. Therefore, the Wilcoxon signed-rank test, a non-parametric alternative to the paired t-test, was used to determine whether there were statistically significant improvements in students' conceptual understanding following the implementation of the CIA. This approach was appropriate given that nonparametric methods are more robust when data do not meet the assumptions of parametric tests, such as normality, and can reduce the risk of incorrect conclusions (Nahm, 2016).In qualitative data analysis, thematic analysis will identify recurring themes in students' insights, such as challenges, engagement, and the relevance of the CIA. The analysis method aligns with best practices for extracting meaning from qualitative data (Braun & Clarke, 2006).

## Results and Discussion

### Validation of the Content of the Contextualized-Interdisciplinary-based Module (CIBM)

Table 6 shows the overall validation ratings given by science experts for the Contextualized-Interdisciplinary-Based Module (CIBM) across five major criteria: Content, Instructional Design and Organization, Assessment and Evaluation, Format, and Language. Each criterion was evaluated for its quality and effectiveness using the mean (M), standard deviation (SD), and corresponding verbal interpretation (VI).

Table 6. Summary of the Science Experts' Validation for Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law in terms of Content Validity

| Criteria | M | SD | VI |
|---|---|---|---|
| 1. Content | 3.877 | 0.233 | VE |
| 2. Instructional Design and Organization | 3.931 | 0.219 | VE |
| 3. Assessment and Evaluation | 3.988 | 0.340 | VE |
| 4. Format | 4.000 | 0.000 | VE |
| 5. Language | 3.940 | 0.966 | VE |
| Average | 3.947 | 0.352 | VE |

*Note: Mean Interpretation, 3.26-4.00=Very Evident (VE), 2.51-3.25=Moderately Evident (ME), 1.76-2.50=Slightly Evident (SE), 1.00-1.175=Not at All Evident (VE)*

The Table 6 shows the overall validation ratings given by science experts for the Contextualized-Interdisciplinary-Based Module (CIBM) across five major criteria: Content, Instructional Design and Organization, Assessment and Evaluation, Format, and Language. Each criterion was evaluated for its quality and effectiveness using the mean (M), standard deviation (SD), and corresponding verbal interpretation (VI).

Among all areas, Format received the highest possible rating, with a mean score of (M=4.000; SD=0.000), reflecting perfect consensus among experts that the module's structure and visual layout are highly appropriate and well-executed. This finding aligns with the study by Inocencio and Calimlim (2021), which emphasized that well-structured instructional materials enhance student engagement and comprehension. This was followed closely by Assessment and Evaluation with a mean score of (M=3.988; SD=0.340), reflecting the adequacy of the activities and questions in measuring student understanding. This is supported by the research of Homillano (2023), who found that validated instructional modules with effective assessment components significantly improve students' cognitive aspects. The Language with a mean score of (M=3.940: SD=0.966) and Instructional Design and Organization with a mean score of (M=3.931; SD=0.210) were both evaluated as “Very Evident”.

While these high scores reflect the overall strength and effectiveness of the module in these areas, the relatively higher standard deviation for Language suggests some variability in the reviewers' perceptions, indicating room for refinement. Specifically, this highlights the need to simplify certain instructions, improve clarity, and ensure consistent use of language throughout the module to enhance student comprehension and accessibility. This insight is particularly important given the self-paced nature of the learning module, where clear and straightforward language is essential to avoid learner confusion. This finding resonates with the seminal work of Alberto (1986), who emphasized that instructional materials must be written in clear, concise, and student-friendly language to support learners' independent understanding and promote cognitive engagement. According to Alberto, complex or overly technical language can hinder learning, especially in science education, where conceptual accuracy must be balanced with learner accessibility. Improving instructional design also involves careful sequencing of content, logical flow of activities, and alignment of learning objectives with assessments. Ensuring that instructions are not only grammatically correct but also pedagogically appropriate and inclusive is vital to support diverse learners, including those with varying levels of scientific literacy. By addressing these areas, future iterations of the module can further strengthen its instructional effectiveness and foster a more meaningful and engaging learning experience for all students.

Lastly, Content with a mean score of (M=3.877; SD=0.233) were likewise rated highly, indicating strong agreement that the module is instructionally sound, well-organized, and content-accurate. His positive evaluation affirms that the learning materials are aligned with curriculum standards, conceptually accurate, and pedagogically relevant to the target learners. These findings are consistent with the study of Acosta (2021), which underscored the importance of ensuring content validity in the development of science learning materials. Acosta emphasized that instructional content must be scientifically accurate, grade-appropriate, and aligned with learning competencies to effectively support students' conceptual understanding. When the content is valid and contextually relevant, it not only enhances the quality of instruction but also fosters deeper student engagement and meaningful learning. Thus, the strong rating in this domain reinforces the credibility and instructional value of the Contextualized-Interdisciplinary-Based Module (CIBM), confirming that it meets essential academic standards while effectively contextualizing scientific principles within real-world applications.

The overall average mean across all criteria is (M=3.9472; SD=0.352), leading to a general verbal interpretation of "Very Evident" (VE). These results indicate that the Contextualized-Interdisciplinary-Based Module (CIBM) is a highly validated and effective educational resource, demonstrating strong alignment with pedagogical standards and supporting high-quality instruction. In the context of science education, such validation is critical as it ensures that instructional materials not only meet academic benchmarks but also promote scientific literacy, critical thinking, and real-world application of concepts. This is further supported by the study of Fabrigas and Taban (2023), which found that contextualization and localization in teaching materials significantly enhance the quality and relevance of instruction. These strategies help make abstract scientific concepts more accessible and meaningful to students, thereby improving engagement and deepening understanding, core goals of effective science teaching. Thus, the CIBM's validation underscores its potential to contribute meaningfully to science education by bridging content knowledge with contextual learning experiences.

Table 7. Inter-rater Reliability Test of Experts' Content Validation of Contextualized-Interdisciplinary-based Module (CIBM) in Charles' Law

| No. of Items | Cronbach's Alpha | Internal Consistency |
|---|---|---|
| 53 | 0.894 | Good |

Table 7 presents the inter-rater reliability results from the expert validation of the CIBM. With 53 items assessed, the Cronbach's Alpha was calculated at 0.894, indicating strong internal consistency among the raters. This suggests a high level of agreement among the experts regarding the module's instructional quality and effectiveness. According to established statistical guidelines, a Cronbach's Alpha in the range of 0.8 to 0.9 signifies a dependable and consistent measurement tool, thereby supporting the credibility of the evaluation outcomes for the CIBM.

The high reliability result is consistent with the findings of Ahmad et al. (2024), who emphasized the importance of Cronbach's alpha in confirming the coherence of research instruments, particularly in educational module development. Their study showed that Cronbach's alpha serves not only as a statistical benchmark but also as a confirmation of item alignment toward unified constructs in curriculum tools. Similarly, Ismail et al. (2025) reported a Cronbach's alpha of 0.97 in their validation of a spiritually-integrated STEM learning module, highlighting how high internal reliability supports the overall readiness of instructional materials for classroom implementation. These findings reinforce the reliability of the CIBM and its potential to deliver consistent learning experiences. For science education, especially within the K to 12 framework, such validated tools are critical in ensuring that students engage with materials that were both pedagogically sound and contextually relevant. Especially In the context of public schools under the Department of Education in the Philippines, where access to well-structured and localized resources is essential, the CIBM provides a dependable instructional option that supports coherent learning pathways in science through interdisciplinary and contextual connections.

**Pretest Mean Score on Conceptual Understanding Test on Charles' Law**

Table 8 displays students' explicit scores in the Conceptual Understanding Test on Charles' Law before the implementation of the Contextualized-Interdisciplinary-based Module (CIBM). This aimed to address SOP 2, which describes the students' conceptual understanding and awareness of Charles' Law and climate change before the intervention.

Table 8. Pretest Mean Score and Standard Deviation on Conceptual Understanding Test on Charles' Law

| Learning Objectives | M | SD | MPS | Verbal Interpretation |
|---|---|---|---|---|
| Learning Objective 1 | 9.240 | 2.203 | 71.714 | Near Proficiency |
| Learning Objective 2 | 5.160 | 1.491 | 73.714 | Near Proficiency |
| Learning Objective 3 | 5.840 | 1.143 | 58.400 | Near Proficiency |
| Charles' Law | 20.240 | 3.370 | 67.467 | Near Proficiency |

*Note: MPS interpretation, 0-24 (no proficiency), 25-49 (low proficiency), 50-74 (near proficiency), 75-89 (proficient), and 90-100 (high proficiency).*

Table 8 presents the pretest scores of students (N=25) in the conceptual understanding test of Charles' Law. Out of 30 items, the students got a total mean of (M=20.240; SD=3.420). This indicates that before being exposed to CIBM, they had a conceptual knowledge of Charles' Law that was considered near proficiency. The overall mean performance score, (MPS=67.467), which falls within the "*Near Proficiency"* level according to the interpretation scale provided.

For Learning Objective 1, which aims to explain the relationship of volume and temperature of greenhouse gases at constant pressure, students achieved a mean score of (M=9.240; SD=2.203), with a mean performance score of (MPS=71.714). This suggests that students were familiar with the basic Charles' law concepts and how temperature affects gas volume, falling under the *"Near Proficiency"* level.

In Learning Objective 2, which involves investigating how the reaction of greenhouse gases to increasing atmospheric temperature contributes to the greenhouse effect and subsequent climate change using virtual simulation, students scored a mean of (M=5.160; SD=1.491), with a mean performance score of (MPS=73.714). Despite a lower mean score, the MPS remains within the *"Near Proficiency"* level, indicating some awareness of the climate-related application of Charles' Law, possibly due to prior exposure or general environmental knowledge.

However, Learning Objective 3, which tasks students to write a reflection on Charles' Law principles and its application to the greenhouse effect and climate change, received the lowest performance, with a mean of (M=5.840; SD=1.143) and mean performance score of (MPS=58.400). Although still categorized under the *"Near Proficiency"* level, these results suggest that students had more difficulty articulating the conceptual and reflective aspects of the lesson, particularly in integrating scientific understanding with real-world environmental issues.

These findings align with previous research emphasizing the effectiveness of interactive simulations in enhancing students' comprehension of complex scientific concepts. This is supported by the work of Thacker and Sinatra (2019), who found that guided online simulations helped students restructure their mental models of the greenhouse effect, leading to improved understanding. Similarly, the use of virtual simulations in teaching these concepts has been shown to enhance student understanding. Evidence from PhET Interactive Simulations (2025) demonstrated that interactive simulations can significantly improve students' grasp of complex scientific phenomena by allowing them to visualize and manipulate variables in real-time scenarios.

Overall, while students demonstrate initial familiarity with Charles' Law and its environmental relevance, the lower scores, especially in reflective and application-based tasks highlight the need for enhanced instructional interventions to deepen both conceptual understanding and critical thinking related to climate science.

**Posttest Mean Score on Conceptual Understanding Test on Charles' Law**

The Table 9 displays students' explicit scores in the Conceptual Understanding Test on Charles' Law before the implementation of the Contextualized-Interdisciplinary-based Module (CIBM). This aimed to address SOP 2, which describes the students' conceptual understanding and awareness of Charles' Law and climate change prior to the intervention.

Table 9. Posttest Mean Score and Standard Deviation on Conceptual Understanding Test on Charles' Law

| Learning Objectives | M | SD | MPS | Verbal Interpretation |
|---|---|---|---|---|
| Learning Objective 1 | 11.520 | 1.531 | 88.615 | Proficient |
| Learning Objective 2 | 6.440 | 0.712 | 92.000 | High Proficiency |
| Learning Objective 3 | 9.120 | 1.269 | 91.200 | High Proficiency |
| Charles' Law | 27.080 | 2.515 | 90.267 | High Proficiency |

*Note: MPS interpretation, 0-24 (no proficiency), 25-49 (low proficiency), 50-74 (near proficiency), 75-89 (proficient), and 90-100 (high proficiency).*

The posttest results for the thirty (30) students in the conceptual understanding test on Charles' law are shown in Table 9. The students received a total mean score (M=27.080; SD=2.515) on the 30-item test. With the implementation of CIBM, learners' conceptual understanding of Charles' law became highly proficient, as shown by their total mean score.

Additionally, the mean score of Learning Objective 1 improved from a mean score of (M=9.240; SD=2.203) in the pretest to a mean score of (M=11.560; SD=1.234) in the posttest, with the mean performance score rising from (MPS=71.714) to (MPS=89.000). This indicates a substantial enhancement in students' grasp of the fundamental concepts of gas behavior. On the other hand, the Learning Objective 2's mean score increased from a mean score of (M=5.160; SD=1.491) to (M=6.920; SD=1.123), and the mean performance score rose from (MPS=73.714) to (MPS=98.857). The significant gain suggests that the use of virtual simulations effectively facilitated students' understanding of the environmental applications of Charles' Law. Lastly, the Learning Objective 3 that encompasses the application of Charles' Law to the greenhouse effect and climate change, significantly increases its mean score from (M=5.840; SD=1.143) to (M=7.360; SD=1.015) with the mean performance score increasing from (MPS=58.400) to (MPS=91.200) and classified to the "*High Proficiency"* level. The improvement indicates progress in students' ability to articulate and reflect on scientific concepts.

The comparative analysis between pretest and posttest results reveals that the instructional interventions, particularly the integration of virtual simulations, had a positive impact on students' understanding of Charles' Law and its applications. The most significant improvement was observed in Learning Objective 2, underscoring the effectiveness of simulation-based learning in facilitating complex scientific investigations.

These findings are similar to the study by Singhasena and Khlaisang (2024), which demonstrated that virtual science simulations on collaborative online platforms significantly enhanced students' scientific inquiry competencies. Their research emphasized the importance of interactive and immersive learning environments in promoting deeper conceptual understanding. Similarly, Liu and Liang (2020) discussed the application of virtual simulation software in university physics teaching, highlighting its effectiveness in enhancing students' conceptual understanding and engagement. The integration of virtual simulations and inquiry-based learning approaches proved effective in enhancing students' comprehension of Charles' Law and its relevance to climate change. While significant improvements were observed in conceptual understanding and investigative skills, further emphasis on developing reflective and application-based competencies is recommended to achieve holistic scientific literacy.

Additionally, the observed improvements align with findings from various studies emphasizing the effectiveness of contextualized and interdisciplinary teaching approaches in science education. Capitolina and Cajurao (2024) developed and validated contextualized lessons in Science, Technology, and Society (STS), demonstrating significant enhancements in students' conceptual understanding, science process skills, and attitudes toward science. Their study reported large effect sizes across all measured outcomes, highlighting the efficacy of contextualized instruction in making scientific concepts more relatable and comprehensible. Similarly, Picardal and Sanchez (2021) conducted a meta-analysis on the effectiveness of contextualization in science instruction in the Philippines. Their findings confirmed that contextualized teaching approaches positively impact students' science literacy and achievement across various educational levels and science domains, reinforcing the value of integrating real-life contexts into science education. Another study conducted by Baraquia (2019), explored the incorporation of interdisciplinary contextualization and inquiry-based learning in science education. The study revealed that such approaches promote critical thinking, deeper understanding, and the ability to connect scientific concepts across different disciplines, thereby enhancing student engagement and learning outcomes.

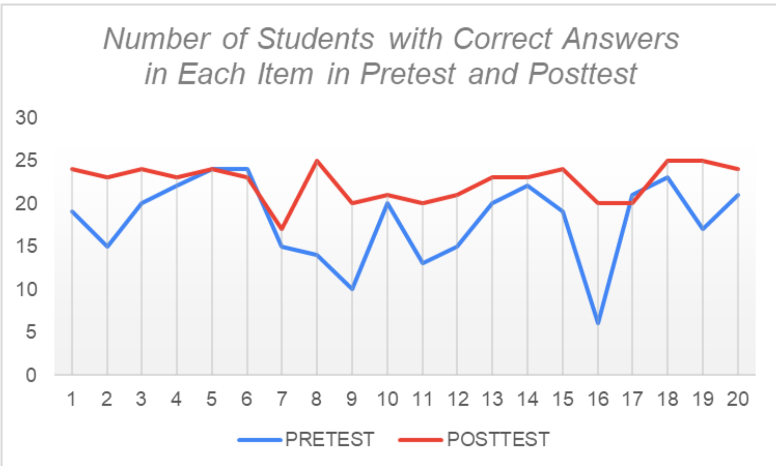


Figure 2. Total Scores of Each Participant in Pretest and Posttest on Charles' Law

Figure 2 shows the total scores of each participant in the pretest and posttest of the conceptual understanding test on Charles' Law. A clear upward trend is seen in most items from pretest to posttest, indicating improved conceptual understanding after the instructional intervention using a Contextualized-Interdisciplinary-based Module (CIBM). Specifically, out of twenty (20) items for the conceptual understanding test on Charles' Law, sixteen (16) items showed notable gains in the number of students who answered correctly after instruction. This improvement can be attributed to the integration of real-world climate change contexts, which helped students see the relevance of Charles' Law beyond abstract concepts. Todd and O'Brien (2016) emphasized that interdisciplinary collaboration, especially when rooted in climate change education, fosters critical thinking and deeper conceptual engagement. Similarly, a study by Brumann et al. (2022) showed that inquiry-based learning in climate education promotes scientific understanding by allowing students to explore real-world phenomena, an approach mirrored in classroom experiments that linked gas laws with atmospheric changes. Windschitl (2023) also advocated for embedding climate change topics across disciplines, enhancing both relevance and retention. Furthermore, Kuo et al. (2011) found that students who blend conceptual insights with mathematical reasoning, as done in climate-data-based investigations, are more likely to develop robust scientific understanding.

However, four (4) out of twenty (20) items showed a decline in posttest scores, which could be due to cognitive overload or insufficient scaffolding within some interdisciplinary activities. Finkelstein (2005) warned that without clear contextual anchors, learners may struggle to apply theoretical knowledge. Likewise, the *Frontiers in Education* journal (2022) noted that while transdisciplinary approaches foster transformative learning, they require careful alignment with students' prior knowledge to avoid confusion. These results highlight the potential for continuous improvement in instructional design, guiding educators to further enhance clarity, support, and engagement. With targeted refinements, such interdisciplinary strategies can yield even greater conceptual gains across all learning indicators.

In conclusion, the marked improvement in students' posttest scores across the targeted learning objectives provides strong evidence that contextualized and interdisciplinary teaching strategies significantly enhance conceptual understanding of Charles' Law and its environmental applications. In terms of application, these results support the growing call in science education to shift from rote memorization to context-driven, problem-based learning. By integrating socio-environmental issues like climate change, educators can create learning experiences that are not only academically rigorous but also socially relevant. By integrating socio-environmental issues such as climate change, educators can create learning experiences that are both academically rigorous and socially relevant. Flener-Lovitt (2014) highlights that embedding global challenges like climate change within chemistry education not only strengthens conceptual understanding but also advances science literacy and prepares learners to tackle pressing environmental issues. Incorporating climate change themes through CIBM thus not only enhances students' grasp of Charles' Law but also cultivates critical scientific thinking and problem-solving skills essential for today's world. These results underscore the need to reimagine science education as an interdisciplinary, context-driven practice that connects fundamental scientific principles with urgent global challenges, making science more meaningful, engaging, and transformative for learners.

**Students' Conceptual Understanding of Charles' Law Before and After Answering the Contextualized-Interdisciplinary-based Module**

Table 10. Wilcoxon Signed-Rank Test for the Difference Between the Students' Pretest and Posttest on Charles' Laws Before and After Exposure to Contextualized-Interdisciplinary-based Module (CIBM)

| N | Before | After | z | r | *p*-value | Verbal Interpretation of r | Decision |
|---|---|---|---|---|---|---|---|
| 60 | 20.240 | 27.080 | -4.940 | 0.638 | 0.000* | Large effect | Reject the $H_0$ |

*Note: significant α=0.05* at N=30, 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).*

According to Table 10, the mean score for the posttest is (M= 27.080; SD= 2.515), whereas the mean score for the pretest was (M = 20.240; SD= 3.420). The Wilcoxon signed-rank test was employed to determine whether there was a significant difference in students' conceptual understanding before and after exposure to the Contextualized-Interdisciplinary-Based Module (CIBM). The test results revealed a statistically significant positive difference between the test scores (z=4.940; p=0.000*) with a large effect size (r = 0.85). This confirms that the use of the CIBM had a substantial positive impact on students' conceptual understanding of Charles' Law, thereby rejecting the null hypothesis.

The improvement in posttest scores suggests that the intervention was not only well-designed and executed but also highly effective in facilitating learning. Students demonstrated deeper comprehension of Charles' Law and its real-world application to environmental issues such as climate change. This finding indicates that the CIBM provided learners with a meaningful context to grasp abstract scientific principles more concretely and critically. These findings are consistent with existing research that emphasizes the effectiveness of contextualized and interdisciplinary approaches in science education. By embedding scientific content within familiar real-life scenarios, students were better able to relate to the material and comprehend complex concepts. These pedagogical strategies that are grounded in real-world relevance and cross-disciplinary integration not only support deeper conceptual understanding but also develop critical thinking abilities. Such competencies are vital for addressing complex, global challenges such as climate change. These findings corroborate the current study's conclusion that integrating real-life applications and cross-disciplinary content fosters deeper learning. The results affirm that contextualized and interdisciplinary modules such as the CIBM serve as powerful educational tools that not only raise achievement scores but also promote critical awareness of global issues like climate change.

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

This section explores how students perceived their experiences with answering the Contextualized-Interdisciplinary-based Module. It fulfills SOP 4 of the research project. In order to gain insights into these perceptions, students completed a student perception questionnaire that captured their thoughts, viewpoints, and overall learning experience throughout the teaching intervention.

**Students' Perception Questionnaire**

After the facilitation of the Students' Perception Questionnaire, four key themes emerged that summarized students' insights and experience in answering the CIBM. The questionnaire mentioned above has been used for the students to share honest feedback on how this approach improves their overall learning experience.

***Theme 1: Making Charles' Law More Understandable and Relevant through Real-World and Interdisciplinary Connections***

Table 11 shows the theme of Improved Conceptual Understanding of Charles' Law through CIBM. This highlights how CIBM cultivates and enhances the participants' conceptual understanding after answering the module.

Table 11. Thematic Analysis of Students' Perception of the Deeper Understanding of Charles' Law

| Theme | Sub-Theme | Code |
|---|---|---|
| Deeper Understanding and Relevancy of Charles' Law | Improved Conceptual Understanding | Enhanced understanding of concepts |
| | | Better retention |
| | Integrated and Active Learning | Interdisciplinary connections |
| | | Meaningful learning |
| | | Interesting and joyful lessons |
| | | Learned better through hands-on activities |
| | | Fun and engaging activities |
| | Real-World Relevance | Real-life situations/scenarios |
| | | Climate-change connection |
| | | Practical examples |

The thematic analysis of the students' perception in Table 11 indicated that the CIBM facilitated a deeper understanding of Charles' Law. Moreover, it demonstrated that students gained and enhanced their understanding of Charles' Law through the relevance of the topic to their everyday life. Contextualized learning transforms abstract concepts into relevant and meaningful knowledge for students, resulting in stronger understanding and better recall. The positive impact of this approach is supported by a study on Science, Technology, and Society (STS) lessons, which found that contextualized materials significantly improved students' conceptual understanding, science process skills, and attitudes toward science (Bello et al., 2023). The approach led to significant gains in students' conceptual understanding of Charles' Law, primarily through clarification and reinforcement of scientific ideas. Improved retention, though less frequent, suggests added value in cognitive durability. Below are the verbatim responses of students that support the sub-theme: "Improved Conceptual Understanding."

Student 11: *"As a student, this surely helps me to understand Charles' Law easier."*

Student 22**:** *"It helps me a lot to the easiest ways, such a easy to read the context, basic to understand and it provides a clear information and learning modules."*

The majority of students acknowledged that the approach helped them better grasp the principles behind Charles' Law. This suggests that the instructional method clarified scientific ideas that might have otherwise remained abstract or difficult to comprehend. A few students noted that the learning experience contributed to longer-lasting retention of knowledge. Although not as frequently mentioned, this implies that the method had a lasting cognitive impact for some learners, potentially due to the clarity and depth of the lessons.

Some students show that active and integrated learning approaches foster meaningful, interdisciplinary, and engaging experiences. While hands-on and fun activities were mentioned less frequently, their inclusion highlights the importance of interactive strategies in sustaining student interest. Below are the verbatim responses of students that support the sub-theme: "Integrated and Active Learning"

Student 3: *"This approach helped me learn Charles' Law by linking it to climate change, which we discuss in other subjects like social studies. I understood how gas volume changes with temperature* *through hands-on activities and graphs, and it made me realize how science affects our environment.*

Student 25: *"The contextualized-interdisciplinary approach helps me understand Charles' Law by connecting it to real-life situations and other subjects, making learning more meaningful and easier to apply."*

As students explored Charles' Law through different subjects, they began to see science as part of a larger story rather than an isolated concept. This approach helped them make sense of the topic in a way that felt real and personal. Many described the learning as fun and engaging, pointing to moments of excitement during experiments or group discussions that made the lessons come alive.

Real-world connections stood out as the most influential sub-theme in promoting deeper understanding. Students strongly benefited from examples and scenarios that made abstract concepts tangible and aligned with current global and personal issues. Below are the verbatim responses of students that support the sub-theme: "Real-World Relevance"

Student 2: "*Using the Contextualized-Interdisciplinary Approach made learning Charles' Law more meaningful. It helped me connect the concept of gas expansion with things I see around me, like how temperature affects weather. I also learned to apply science in real-life problems, which made the topic easier to understand and remember*."

Student 18: *"It approach me to have deeper comprehension such as real-world connections, connecting it to a climate change. Understanding the Charles Law by connecting real-world phenomena."*

The most frequently cited code indicates that contextualizing Charles' Law in everyday life significantly enhanced student understanding. This relevance helped students see the importance and application of scientific concepts beyond the classroom. Many of the students' responses showed appreciation between Charles' Law and climate change, showing that environmental contexts made the topic more urgent and meaningful. Also include examples that illustrate how the concept applied to their daily routines and observations. Students' responses revealed that students perceived a significantly deeper understanding of Charles' Law when taught using a contextualized and interdisciplinary approach. Three key themes emerged: Improved Conceptual Understanding, Integrated and Active Learning, and Real-World Relevance. These themes emphasize how conceptual clarity, meaningful and engaging activities, and connections to real-life scenarios, including climate change, enhance students' grasp of the topic. The responses affirm that students learn science more effectively when the content is relatable, hands-on, and connected to broader societal issues. Climate-related science education has gained importance in recent years. Duschl and Bismack (2022) argue that linking scientific concepts to pressing societal issues like climate change enhances students' motivation and fosters scientific literacy, particularly in middle and secondary education. This approach adds to the expanding body of research supporting science education reforms that emphasize contextual relevance, active learning, and interdisciplinary integration are the key elements in preparing students for academic achievement and real-world application of scientific knowledge.

***Theme 2: Enhancing Engagement by Connecting Charles' Law to Real-World Issues***

The Table 12 shows the theme of Linking Charles' Law to Real-World Issues through CIBM. This theme captures students' reflection on how linking Charles' Law to real-world environmental concerns, particularly climate change, heightened their interest and engagement in learning. The integration of relevant, real-life scenarios fostered a sense of purpose and relevance, reinforcing the value of science education beyond the classroom.

Table 12. Thematic Analysis of Students' Perception of Linking Charles' Law to Real-World Issues

| Theme | Sub-Theme | Code |
|---|---|---|
| Linking Charles' Law to Real-World Issues | Engagement and Reflective Learning | Increased engagement |
| | | Meaningful learning |
| | | Awareness of global/environmental issues |
| | | Motivation to take action |
| | Real-World Relevance | Real-life relevance |
| | | Practical examples |
| | | Practical application of scientific concepts |

The thematic analysis of the students' perception in Table 12 indicated that the CIBM exhibited enhanced engagement among the participants. The theme most cited was Real-life relevance, closely followed by Practical examples and Practical application of scientific concepts, all testifying to a high appreciation for the experience of learning connected with everyday life. There were also several increased Engagement, Meaningful learning, and Awareness of environmental issues, stating that the interdisciplinarity stimulated more profound understanding and awareness. Some of the students' exact answers are listed here:

> Student 18: *"I find it more interesting because I learn more about Charles law by just connecting it to real-world, urgent problems like climate change. It illustrates how it is applied in real-world situations and how they affect the environment."*
>
> Student 20: *"Using real-world issues like climate change makes learning Charles' Law more engaging and meaningful. It helps me see the practical applications of science and how the concepts I learn can directly affect the environment and society, making the learning experience more impactful."*
>
> Student 25: *"Using real-world issues like climate change to learn Charles' Law makes the lesson more relevant and engaging. It helps me see the importance of science in everyday life and understand its real impact."*

Some students even reported feeling inspired to act, demonstrating that the lessons went beyond the academic material to affect their personal values and consciousness. The student's actual answers are listed below.

> Student 2: *" Learning Charles' Law through climate change made it easier for me to understand because I can relate it to things I see in the news or in my environment. It also helped me realize how science can explain real problems and encourage solutions."*
>
> Student 3: *"I feel more engaged when we use real-world issues like climate change to study Charles' Law. It shows how science works in everyday life, and it makes me want to learn more about how I can help take care of the planet."*

These findings are supported in the study of Valderrama et al. (2024), which highlights the pedagogical advantages of merging physics with environmental education. Their study indicates that linking physics concepts such as Charles' Law to actual environmental concerns not only solidifies learning but also renders it more meaningful and life-long learning. The CIBM proved this impact in practice by making many of the lessons not only intellectually stimulating but also personally meaningful. In addition, there were even students who professed their willingness to make a difference, reflecting that the knowledge reached beyond the classroom and into their values and environmental awareness. Similarly, Kim (2024) demonstrated that connecting chemistry concepts to climate change through experiential learning significantly enhanced students' environmental awareness and encouraged them to take proactive action, further validating the strength of interdisciplinary and context-based instruction. This is related locally in the study of Aruta (2022) , which revealed that science literacy, when integrated with climate change education, promotes energy-conserving behaviors and responsible decision-making. By linking Charles' Law to pressing concerns such as climate change, the CIBM has been demonstrated to be an effective pedagogical tool for building both scientific and environmental literacy, ultimately enabling students to think critically and act responsibly in the face of global challenges.

***Theme 3: Affordances of the Contextualized-Interdisciplinary-based Module to Students' Conceptual Understanding of Charles' Law***

Table 13 shows the theme about how the Contextualized-Interdisciplinary-based Module (CIBM) helped students in different ways, especially in making concepts clearer and learning experiences more engaging and hands-on. The results highlight how the module supported students in understanding Charles' Law better by using real-world connections and interactive learning methods.

Table 13. Thematic Analysis of Students' Perception of the Affordances of the CIBM

| Theme | Sub-Theme | Code |
|---|---|---|
| Advantages of the CIBM | Improved Conceptual Clarity | Easier understanding |
| | | Clearer concepts |
| | | Better retention |
| | Experiential and Visual Learning | Hands-on learning /experiences |
| | | Visual observation |
| | | Real-time results |
| | Increased Engagement and Enjoyment | Fun and interesting |
| | | Joyful learning |
| | Applied Understanding | Real-world connection |

The thematic analysis of the students' responses in Table 13 showed that the CIBM helped improve their engagement and understanding throughout the learning process. The most frequently mentioned theme was Improved Conceptual Clarity, followed by Experiential and Visual Learning and Increased Engagement and Enjoyment, which all reflect how much the students appreciated a learning experience that was hands-on, easier to understand, and more enjoyable. Some students also mentioned Applied Understanding, highlighting how the module helped them see the connection between the topic and real-life situations. Below are the precise responses given by the students:

Student 6: *"Doing experiments or activities helped me understand Charles' Law better because I could see how gases really expand when heated. It made the lesson more fun and easier to remember since I was learning by doing, not just reading or listening."*

Student 20: *"Experiments allowed me to observe Charles' Law in action, such as watching how heated gases expand. This hands-on experience made the law more tangible and helped solidify my understanding of how temperature affects gas volume."*

The students' responses show that the Contextualized-Interdisciplinary-based Module (CIBM) helped them understand Charles' Law better by making the lesson more concrete, visual, and easier to relate to. This is supported by the study of Rivera and Sanchez (2020), which found that contextualized instructional materials helped students learn gas laws more effectively by connecting the lesson to real-life situations and using hands-on activities. Tufino et al. (2024) also highlighted how active learning through experiments, like those in the ISLE framework, allows students to observe physical changes directly, helping them build a stronger understanding of scientific ideas. Zarei (2022) also showed that simple experiments helped middle school students understand and remember how gas variables are related. Sweeder et al. (2021) added that using simulations and videos made it easier for learners to form better mental images of how gases behave on a molecular level. All these studies support how modules like the CIBM, which are experiential, contextualized, and interdisciplinary, can lead to deeper learning. In the Philippines, using modules like this could help improve how science is taught by making lessons more meaningful and connected to students' daily lives. It can also make science concepts easier to understand and remember, which may lead to better performance and interest in science among Filipino students.

***Theme 4: Encumbrances Encountered by the Students***

Table 14 presents the different learning challenges that students encountered while engaging with the Contextualized-Interdisciplinary-based Module (CIBM). Although the module offered various benefits, some students still experienced minor difficulties, especially related to time management and learning conditions. These challenges are natural and expected when implementing new strategies, especially in a classroom setting with diverse learners.

Table 14. Thematic Analysis of Students' Perception of the Challenges Experienced during the Implementation of the CIBM

| Theme | Sub-Theme | Code |
|---|---|---|
| Encountered Learning Challenges | Cognitive Expression Challenges | Trouble expressing ideas or opinions |
| | Time and School Activity Conflicts | Time constraints |
| | | Schedule conflicts |
| | Learning Environment Limitations | Lack of face-to-face interaction |
| | | Online and remote barriers |

As shown in Table 14, the most common challenges were related to time constraints and schedule conflicts, with both being reported six times each. A few students also found it a bit challenging to express their thoughts clearly, particularly when sharing their ideas during discussions or written tasks. Moreover, there were mentions of limitations related to the learning environment, like the lack of face-to-face interaction and some barriers in online or remote setups. Below are the exact responses provided by the students:

> Student 3: *"I struggle with the limited time for activities and the lack of face-to-face interaction during lessons."*
>
> Student 4: *"When I had to formulate my own opinion about the topic because it's hard for me to think about the right words."*
>
> Student 8: *"It was hard to focus and keep up with the lesson when there were so many things happening at school."*
>
> Student 12: *"One challenge I encountered during the lesson was a lack of time because of other school activities."*
>
> Student 24: "*There is a limited time to answer the module because we are preparing for the exams and practice for cheerdance."*

The students' responses indicate that while the Contextualized-Interdisciplinary-Based Module (CIBM) was generally effective, they still encountered certain challenges, particularly with time management, cognitive expression, and limitations in the learning environment. These findings are supported by the study of Bayron (2023), which revealed that secondary students in modular learning environments struggled with managing their time due to overlapping academic tasks, unclear instructions, and the absence of direct teacher guidance. Toquero (2020) also emphasized that students often found it difficult to express their ideas clearly in remote learning settings, as the sudden shift to independent study reduced opportunities for interaction and real-time feedback. Lastly, the lack of face-to-face engagement and online learning barriers identified in this study are echoed by Barrot et al. (2021), who found that students experienced feelings of isolation, technical difficulties, and decreased motivation during online classes in the Philippine context. These existing studies reinforce the idea that while modules like CIBM offer meaningful learning experiences, the challenges that surfaced can serve as valuable insights for further improving science instruction. With these issues being identified, they can now be addressed through better module design, clearer guidance, and improved learner support. In the long run, this can contribute to making science education in the Philippines more responsive, engaging, and effective for a wider range of students.

## Conclusion

This study concludes that the Contextualized-Interdisciplinary-Based Module (CIBM) is an effective pedagogical tool for enhancing students' conceptual understanding of Charles' Law. The module was rated "Good" across all evaluation criteria by experts in science, language, and technology, demonstrating strong alignment with curriculum standards, age-appropriate language use, and effective digital integration. Pre-test results revealed that students initially had limited understanding of gas behavior and its connection to real-world environmental issues, particularly climate change. Post-test outcomes, however, showed marked improvement in their ability to explain and apply Charles' Law in meaningful contexts, indicating a significant gain in conceptual understanding. This improvement can be attributed to the Contextualized-Interdisciplinary Approach (CIA), which effectively bridged theoretical content with relevant, real-life phenomena. Students also perceived the approach as engaging, relevant, and supportive of deeper learning, underscoring its potential to address misconceptions while fostering interest and critical thinking. Overall, the findings affirm that integrating interdisciplinary content, contextualized instruction, and technology-enhanced learning can promote meaningful and holistic science education in the Philippine Grade 10 curriculum.

## Recommendations

Based on the findings and conclusions of this study, several recommendations are offered for future research and practice. To address students' initial difficulties in understanding the volume–temperature relationship in Charles' Law, it is recommended that future instruction incorporate more hands-on and real-life learning experiences using contextualized and interdisciplinary approaches. Activities such as simulations, experiments, and real-world problem scenarios can make abstract scientific principles more relatable, fostering deeper conceptual understanding and learner engagement. Future studies are also encouraged to adopt a longitudinal design to examine the sustained impact of the module not only on conceptual understanding, but also on students' retention, higher order thinking skills, and ability to apply knowledge in environmental decision-making contexts. Additionally, given the observation that some items in the conceptual test yielded unexpectedly higher pretest scores than posttest scores, a detailed item analysis is recommended to evaluate the reliability, validity, and overall effectiveness of the assessment tool. Revising or replacing problematic items will ensure more accurate measurement of learning gains. Student feedback also highlighted the need to improve clarity in some activity instructions and to include more interactive simulations. Thus, refining instructional materials to be more concise, student-friendly, and aligned with intended learning outcomes is advised, along with incorporating additional simulations to accommodate diverse learning styles and enhance engagement. Moreover, due to implementation challenges linked to class disruptions during the fourth quarter, it is recommended that future studies schedule the intervention earlier in the academic year to allow for more stable participation and deeper learning. Finally, considering the positive outcomes of the Contextualized-Interdisciplinary-Based Module (CIBM), future researchers and educators are encouraged to adapt this approach across other science disciplines such as Biology, Physics, and Earth Science, and even in non-science subjects, to promote meaningful learning, real-world connections, and holistic student development.

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