Article

Volume 22 (2026), pp. 53-71
American Journal of STEM Education: Issues and Perspectives
eISSN 30.3-1190| Print ISSN: 3069-0072
Star Scholars Press
https://doi.org/10.32674/pzhze917

Prerequisite Chemistry Knowledge as a Predictor of Senior High School Students' Achievement in Thermochemistry

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ABSTRACT

This study examined whether students' mastery of prerequisite chemistry concepts predicts their achievement in thermochemistry. Using a quantitative correlational design, data were collected from 90 second-year science students in public senior high schools in the Cape Coast Metropolis, Ghana. Prerequisite knowledge was measured using a Prerequisite Concepts Achievement Test (PCAT), while thermochemistry achievement scores were obtained from continuous classroom-based assessments. Data were analyzed using descriptive statistics and Pearson's product–moment correlation. Results revealed a very strong positive and statistically significant relationship between prerequisite knowledge and thermochemistry achievement ($r = .953$, $p < .001$). The coefficient of determination ($r^2 = .908$) indicates that mastery of foundational concepts accounts for a substantial proportion of variance in thermochemistry performance. These findings reinforce the hierarchical nature of chemistry learning and underscore the importance of diagnostic assessment, curriculum sequencing, and targeted remediation in strengthening students' conceptual readiness for advanced chemistry topics.

Keywords: Chemistry education; conceptual understanding; foundational concepts; prerequisite knowledge; senior high school students; STEM education; thermochemistry achievement

Editors: Oswaldo Castro Romero, Universidad Vizcaya de las Américas, Mexico

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INTRODUCTION

Students' achievement in advanced chemistry topics is strongly influenced by their mastery of prerequisite concepts, making prior knowledge a central concern in chemistry education research. This relationship is particularly critical in thermochemistry, a topic that requires learners to integrate foundational ideas with abstract representations of energy changes in chemical systems. Thermochemical concepts develop cumulatively from earlier chemistry knowledge, and students who lack a solid conceptual base often experience persistent learning difficulties (Tümay, 2016). As Talanquer (2010) notes, chemical knowledge is inherently hierarchical, meaning that understanding complex ideas depends on well-developed foundational concepts. This perspective is consistent with constructivist learning theories, which emphasize that new knowledge is constructed upon existing cognitive structures (Piaget, 1973; Vygotsky, 1978).

In thermochemistry instruction, prerequisite concepts such as atomic structure, periodic trends, chemical bonding, and the particulate nature of matter serve as essential building blocks for understanding energy transformations and reaction energetics (Becker & Cooper, 2014). Empirical studies have shown that students with a weak understanding of these foundational concepts struggle to grasp thermochemical ideas such as enthalpy change, bond energy, and thermochemical equations (Cracolice & Busby, 2015). Because thermochemistry requires students to reason at the submicroscopic level, inadequate prerequisite knowledge often leads learners to rely on rote memorization rather than conceptual understanding, limiting meaningful learning and transfer (Dreyfus et al., 2014).

Beyond content mastery, prerequisite knowledge plays a vital role in the development of scientific reasoning and problem-solving skills, which are core competencies in STEM education. According to Krajcik et al. (2014), students must be able to apply their understanding of atomic and molecular interactions to explain energy changes, predict reaction outcomes, and interpret thermodynamic processes. When these foundations are insufficient, students are more likely to develop fragmented knowledge and alternative conceptions, which persist despite instruction (Talanquer, 2010). Such conceptual weaknesses hinder students' ability to engage productively with the integrative and abstract nature of thermochemistry.

Research has consistently shown that many students begin advanced chemistry topics without adequate conceptual readiness, negatively affecting their learning outcomes (Musengimana et al., 2021). These gaps in prerequisite understanding often result in cumulative learning difficulties, as misconceptions formed in earlier topics compound over time (Taber, 2013). Thermochemistry poses a particular challenge because it requires the simultaneous application of multiple prior concepts while introducing new abstract ideas such as entropy, Gibbs free energy, and enthalpy (Sokrat et al., 2014). Without strong foundational knowledge, students find it difficult to construct coherent mental models of these concepts.

Understanding the relationship between students' prerequisite knowledge and their achievement in thermochemistry has important implications for STEM curriculum design, instructional planning, and learner support. Establishing a strong relationship would suggest that improving students' mastery of foundational chemistry concepts could substantially enhance their performance in thermochemistry and related STEM disciplines (Raker & Holme, 2014). Additionally, identifying this relationship can inform the use of diagnostic assessments to detect learning gaps early and implement timely instructional interventions (Button et al., 2023).

Therefore, the purpose of this study is to examine whether students' achievement in prerequisite chemistry concepts predicts their achievement in thermochemistry. The study was guided by the following research question:

RQ: What is the relationship between senior high school students' mastery of prerequisite chemistry concepts and their achievement in thermochemistry?

By statistically analyzing this relationship, the study seeks to provide empirical evidence supporting the role of prior knowledge in chemistry learning and contribute to the broader discourse on effective STEM instruction. The findings are expected to guide educators in designing instructional strategies that ensure students develop strong conceptual foundations before engaging with advanced chemistry topics.

LITERATURE REVIEW

Understanding how students' mastery of prerequisite chemistry concepts influences their achievement in thermochemistry has been a persistent concern in chemistry education research. Thermochemistry is widely regarded as one of the most conceptually demanding topics in the chemistry curriculum because it requires learners to integrate multiple foundational concepts, such as atomic structure, chemical bonding, molecular interactions, and energy principles, within abstract representational frameworks. Consequently, students' success in thermochemistry is closely tied to the quality and coherence of their prior conceptual knowledge. This section reviews the theoretical foundations underpinning this relationship, examines empirical evidence on prerequisite knowledge and chemistry achievement, and identifies gaps that the present study seeks to address.

Theoretical Foundations of Prerequisite Knowledge in Chemistry Learning

Constructivist Theory and the Hierarchical Nature of Chemical Knowledge

Constructivist learning theory provides a foundational framework for understanding the role of prerequisite knowledge in thermochemistry learning. According to Piaget (1973), learners actively construct new knowledge by assimilating it into existing cognitive structures, while Vygotsky (1978) emphasizes the importance of scaffolding and the Zone of Proximal Development in advancing learning from familiar to more complex ideas. Within this framework, meaningful learning in thermochemistry depends on the availability of well-developed prerequisite concepts that can support the construction of new understanding.

Chemistry knowledge itself is inherently hierarchical and cumulative in nature (Talanquer, 2013). Students typically progress from understanding particulate-level concepts to symbolic representations and finally to macroscopic phenomena, often described as the chemistry triplet. Thermochemistry requires students to coordinate all three levels simultaneously—for example, relating molecular bond energies to symbolic thermochemical equations and observable heat changes. When prerequisite knowledge is weak or fragmented, students struggle to move fluently across these representational levels, resulting in superficial or rote learning rather than deep conceptual understanding.

Cognitive Load Theory and Prior Knowledge

Cognitive Load Theory further explains why prerequisite knowledge is critical for learning thermochemistry. Sweller (1988) argues that learning complex material places high demands on working memory, and that well-developed schemas in long-term memory are essential for reducing cognitive load. Thermochemistry tasks often require students to process symbolic equations, particulate-level energy changes, and macroscopic observations simultaneously. Without strong prerequisite schemas, such as an understanding of bonding, molecular interactions, and energy changes, students are more likely to experience cognitive overload (Sweller et al., 2019). This overload can lead to misconceptions, procedural errors, or an overreliance on memorization, limiting conceptual understanding and transfer.

Importance of Prerequisite Chemistry Concepts for Thermochemistry

Several foundational chemistry concepts serve as essential prerequisites for understanding thermochemical principles. Atomic structure and electron configuration explain why chemical bonds form and why energy is released or absorbed during reactions. Chemical bonding and molecular interactions underpin students' understanding of bond enthalpy, reaction energetics, and energy profile diagrams (Becker & Cooper, 2014). Similarly, the particulate nature of matter allows learners to visualize energy changes at the molecular level, while periodicity supports explanations of trends in reactivity and stability that influence enthalpy changes.

Intermolecular forces are particularly important for understanding enthalpies of phase changes and physical transformations, while hybridization and molecular geometry contribute to explanations of molecular stability and associated energy changes. Students who lack mastery of these concepts often struggle to interpret thermochemical equations, distinguish between endothermic and exothermic processes, or connect symbolic representations with particulate-level explanations (Dreyfus et al., 2014). These difficulties highlight the central role of prerequisite knowledge in shaping students' thermochemistry learning experiences.

Beyond conceptual understanding, prerequisite knowledge also supports the development of scientific reasoning and problem-solving skills essential for thermochemistry. Bain et al. (2014) demonstrated that students' ability to reason about energy changes is strongly influenced by their understanding of chemical structure and molecular interactions. Students with strong foundational knowledge are better able to predict reaction energetics, interpret thermodynamic data, and solve both qualitative and quantitative problems. In contrast, students with weak prerequisite knowledge often rely on rote memorization, resulting in fragile knowledge structures that cannot be applied effectively to novel or complex situations.

Empirical Evidence on Prerequisite Knowledge and Chemistry Achievement

Empirical studies consistently report that many students' difficulties in thermochemistry stem from weaknesses in prerequisite knowledge. Misconceptions related to heat and temperature, bond energy, and chemical bonding are particularly prevalent and have been shown to interfere with students' understanding of thermochemical concepts (Cracolice & Busby, 2015; Luxford & Bretz, 2014; Stylos et al., 2021; Tsaparlis et al., 2018). For example, students who fail to distinguish between heat and temperature often misinterpret calorimetric data, while misconceptions about bond energy lead to incorrect reasoning about why reactions release or absorb energy.

Chemistry is a cumulative discipline, and difficulties with foundational concepts tend to compound over time. Taber (2013) notes that early conceptual gaps become increasingly problematic as students encounter more advanced topics. Musengimana et al. (2021) further observed that students' confidence in their foundational knowledge significantly influences both their attitudes toward chemistry and their academic performance. Students with weak prerequisite understanding are more likely to perceive thermochemistry as inaccessible, leading to disengagement and reliance on memorization rather than conceptual reasoning.

Thermochemistry is particularly sensitive to cumulative learning difficulties because it demands the integration of multiple prerequisite concepts simultaneously. Sokrat et al. (2014) found that students often struggle with thermochemical and thermodynamic ideas precisely because these topics require concurrent application of knowledge from bonding, stoichiometry, molecular structure, and energy principles. When prerequisite knowledge is fragmented, students struggle to connect symbolic equations with molecular-level explanations or interpret enthalpy diagrams accurately.

A growing body of research further confirms that prior knowledge is a strong predictor of success in thermochemistry and related topics. Becker and Cooper (2014) demonstrated that students' understanding of molecular potential energy strongly influences their achievement in thermodynamic contexts. Raker and Holme (2014) similarly reported that familiarity with foundational chemistry concepts enhances students' ability to process and solve complex problems involving energy transformations. Button et al. (2023) showed that expert chemists rely heavily on well-organized foundational knowledge when reasoning through unfamiliar problems, highlighting the disadvantage faced by students who lack such conceptual grounding.

Recent research in chemistry education continues to emphasize the importance of conceptual understanding in thermodynamics and thermochemistry learning. For example, Stylos et al. (2021) demonstrated the persistence of misconceptions related to thermal concepts among science learners, highlighting the need for strong foundational knowledge. Button et al. (2023) further showed that successful scientific reasoning depends heavily on well-organized prior knowledge structures. Studies in chemical education research also indicate that students' ability to connect molecular-level explanations with symbolic and macroscopic representations is essential for understanding energy-related chemical phenomena (Cooper et al., 2017; Talanquer, 2017). These findings reinforce the importance of examining prerequisite chemistry knowledge as a predictor of thermochemistry achievement.

Implications for Curriculum and Instruction

The reviewed literature underscores the importance of aligning thermochemistry instruction with students' prerequisite knowledge. Strong evidence suggests that improving mastery of foundational concepts before introducing thermochemistry can enhance learning outcomes. Diagnostic assessments may be used to identify conceptual gaps early, allowing for targeted remediation. Curriculum sequencing should emphasize coherent conceptual progressions, ensuring that topics such as bonding, particulate theory, and periodicity are adequately mastered prior to thermochemistry instruction. Instructional strategies that emphasize conceptual connections and scaffold learning across topics are particularly important given the integrative nature of thermochemistry.

Research Gap and Summary

Although existing studies clearly establish the importance of prerequisite knowledge for chemistry learning, many investigations focus on specific misconceptions or isolated conceptual domains. Fewer studies quantitatively examine the strength of the relationship between students' overall mastery of prerequisite chemistry concepts and their achievement in thermochemistry, particularly within senior high school contexts in sub-Saharan Africa. There is a need for empirical evidence that explicitly measures this relationship using achievement data drawn from authentic classroom assessments.

In summary, the literature demonstrates that thermochemistry is a hierarchical and cognitively demanding topic that depends heavily on strong foundational knowledge. Constructivist and cognitive load theories provide a robust theoretical basis for understanding this dependency, while empirical studies consistently show that weak prerequisite knowledge leads to poor performance and persistent misconceptions. This study addresses an important gap by statistically examining the relationship between students' mastery of prerequisite chemistry concepts and their achievement in thermochemistry, thereby contributing context-specific evidence to the broader STEM education literature.

RESEARCH METHOD

Research Design

This study employed a quantitative correlational research design to examine the relationship between students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry. The design focused on determining the strength and direction of association between the two variables using numerical achievement data obtained under natural classroom conditions. No instructional intervention or manipulation of variables was undertaken.

The correlational design was appropriate because the study sought to establish whether variations in students' mastery of foundational chemistry concepts were statistically related to their performance in thermochemistry, rather than to infer causal effects. This approach is widely used in chemistry and STEM education research when investigating relationships among academic achievement variables.

Population and Sample

The population for the study consisted of second-year General Science students in public senior high schools within the Cape Coast Metropolis, Ghana. The sample comprised 90 SHS2 science students selected from three public senior high schools. These schools operate under the Ghana Education Service (GES) and follow the national chemistry syllabus.

Participants were selected using purposive and convenience sampling techniques. Purposive sampling ensured that students had received instruction in the prerequisite chemistry topics relevant to thermochemistry, while convenience sampling was applied based on accessibility and administrative approval. The sample size was considered adequate for Pearson correlation analysis and consistent with similar studies in chemistry education.

Instructional Context

Students received thermochemistry instruction from their regular chemistry teachers in their respective schools. Instruction was not centralized under a single teacher. All instruction followed the national Senior High School chemistry syllabus prescribed by the Ghana Education Service, ensuring consistency in content coverage across schools. However, the exact duration of thermochemistry instruction was not standardized or explicitly documented, as teaching followed normal school schedules.

Instruments

Prerequisite Concepts Achievement Test (PCAT)

The Prerequisite Concepts Achievement Test (PCAT) was used to assess students' mastery of foundational chemistry concepts necessary for understanding thermochemistry. The test covered the following content areas:

- Particulate nature of matter
- Atomic structure and electron configuration
- Periodicity
- Interatomic and intermolecular bonding
- Hybridization and molecular geometry

The PCAT consisted of 20 items, combining structured and multiple-choice questions designed to assess both conceptual understanding and application skills. Students were required to answer all items within 25 minutes. The test was aligned with the Senior High School chemistry curriculum and reflected concepts taught prior to and alongside thermochemistry.

The PCAT was administered after thermochemistry instruction had been completed; however, it assessed foundational concepts that had been taught in earlier units prior to thermochemistry. The timing ensured that students' prerequisite knowledge reflected retained conceptual understanding rather than short-term pretest performance. Nonetheless, the post-instruction administration may have allowed limited reinforcement effects, which is acknowledged as a methodological limitation.

Thermochemistry Achievement Measure

Students' achievement in thermochemistry was assessed using continuous classroom-based assessments rather than a researcher-developed standardized test. Achievement data were drawn from students' regular instructional records, ensuring that performance reflected authentic classroom learning.

The thermochemistry achievement measure comprised:

- Two exercises (20 marks each)
- Two quizzes (40 marks each)
- Two projects (40 marks each)

All assessment tasks focused exclusively on thermochemistry-related content, including exothermic and endothermic reactions, enthalpy changes, thermochemical equations, bond enthalpy calculations, and energy profile diagrams. These tasks were teacher-developed, and no departmental or inter-school standardization of assessment rubrics was specified.

Scoring Procedure

For each student, scores from the selected exercises, quizzes, and projects were aggregated to obtain a raw total score out of 200 marks, calculated as follows:

- Exercises: $2 \times 20 = 40$
- Quizzes: $2 \times 40 = 80$
- Projects: $2 \times 40 = 80$
- Total = 200 marks

To facilitate statistical analysis and comparability, each student's raw score was converted to a normalized score out of 40 using a scaling formula. The normalized scores were subsequently categorized into performance levels, and frequency distributions were computed to describe overall achievement in thermochemistry.

Validity and Reliability

Content validity of the instruments was established through expert review by experienced chemistry educators from the University of Education, Winneba. The reviewers examined the PCAT and the thermochemistry assessment tasks for clarity, curriculum alignment, and coverage of essential concepts. Minor revisions were made based on their feedback.

Reliability of the PCAT was established through a pilot study involving 30 SHS students from a school not included in the main study. Internal consistency reliability was estimated using Cronbach's alpha, yielding a coefficient of $\alpha = 0.78$, which is acceptable for educational research.

For the thermochemistry achievement measure, reliability was supported through the aggregation of multiple classroom-based assessments administered over time. Combining exercises, quizzes, and projects reduced the influence of single-assessment variability and enhanced score stability. While common marking rubrics across schools were not specified, the composite nature of the measure provided a broader and more reliable representation of students' thermochemistry achievement than reliance on a single test.

Data Collection Procedures

Ethical clearance was obtained from the Institutional Review Board of the University of Education, Winneba, and additional permission was secured from school heads and heads of science departments in the participating schools. Students were informed about the purpose of the study, assured of confidentiality, and participation was voluntary.

Data collection occurred in two stages. First, the PCAT was administered to SHS2 science students under normal classroom conditions, and responses were marked using a standardized marking guide. Second, students' thermochemistry achievement data were extracted from classroom assessment records, comprising exercises, quizzes, and projects completed during thermochemistry instruction. Scores were aggregated and normalized prior to analysis. Data collection was conducted during the second term of the 2023/2024 academic year, immediately after completion of the thermochemistry unit.

Data Analysis

Quantitative data were analyzed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics, including means, standard deviations, and score distributions, were computed to summarize students' performance in prerequisite concepts and thermochemistry.

To examine the relationship between students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry, Pearson's product–moment correlation coefficient (r) was computed. Statistical significance was tested at $\alpha = 0.05$, and results were presented using tables and narrative interpretation.

Ethical Considerations

All ethical guidelines for educational research were observed. Participation was voluntary, informed consent was obtained, student identities were anonymized, and data were used solely for research purposes.

RESULTS

Text Students' Achievement in Prerequisite Chemistry Concepts

Students' achievement in prerequisite chemistry concepts was assessed using the Prerequisite Concepts Achievement Test (PCAT). The test measured students' knowledge of the particulate nature of matter, atomic structure, periodicity, interatomic and intermolecular bonding, and hybridization and molecular shapes. The distribution of students' scores on the PCAT is presented in Table 1.

Table 1
Students' Scores on the Prerequisite Concepts Achievement Test (PCAT)

Score Range	Frequency	Percent
0–10	35	33.3

11–19	30	27.8
20–29	15	22.2
30–35	5	11.1
36–40	5	5.6
Total	90	100.0

Note. Mean = 17.01; SD = 3.63

Students' Achievement in Thermochemistry

Students' achievement in thermochemistry was obtained from continuous classroom-based assessments comprising exercises, quizzes, and projects related exclusively to thermochemistry content. Aggregated and normalized scores were categorized according to established performance criteria. The distribution of students' thermochemistry achievement scores is shown in Table 2.

Table 2
Students' Thermochemistry Achievement Scores

Score Range	Frequency	Percent
0–10	29	32.2
11–19	30	33.3
20–29	18	20.0
30–35	5	5.5
36–40	8	8.9
Total	90	100.0

Note. Mean = 16.67; SD = 3.60

Relationship Between Prerequisite Knowledge and Thermochemistry Achievement

Pearson's product–moment correlation analysis was conducted to examine the relationship between students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry. The results of the analysis are presented in Table 3.

Table 3
Pearson Correlation Analysis Between PCAT Scores and Thermochemistry Achievement

Statistic	Value
Pearson correlation coefficient (r)	.9530

Coefficient of determination (r^2)	.9082
p-value	< .0001
Sample size (n)	90
Degrees of freedom	88
95% Confidence Interval for r	[.9292, .9690]
Standard error of r	.0102
t-statistic	29.6843

Summary of Results

The results showed that students' scores in both the prerequisite concepts test and thermochemistry achievement were distributed across low to high performance categories. Pearson correlation analysis revealed a very strong, positive, and statistically significant relationship between students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry.

DISCUSSION

This study examined the relationship between students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry. The findings revealed an exceptionally strong positive correlation ($r = .9530$, $p < .0001$), indicating that students' mastery of foundational chemistry concepts is closely associated with their performance in thermochemistry. This result provides strong empirical support for the hierarchical nature of chemistry learning, where understanding advanced topics depends substantially on prior conceptual knowledge.

The generally low to moderate performance observed in both the prerequisite concepts test and the thermochemistry achievement measure suggests that a considerable proportion of students lacked the foundational understanding required for meaningful engagement with thermochemistry. More than half of the students demonstrated limited mastery of prerequisite concepts such as atomic structure, chemical bonding, and the particulate nature of matter. These weaknesses appear to have extended into thermochemistry, where a similar pattern of achievement was observed. This parallel distribution of scores highlights the cumulative nature of learning difficulties in chemistry, whereby gaps in foundational understanding persist and influence students' performance in subsequent topics.

The strength of the relationship between prerequisite knowledge and thermochemistry achievement is consistent with constructivist theories of learning, which emphasize that new knowledge is constructed upon existing cognitive structures (Piaget, 1973; Vygotsky, 1978). When students lack well-developed foundational schemas, they are less able to integrate abstract thermochemical concepts such as enthalpy changes, energy profiles, and bond enthalpy calculations. In such cases, learners may resort to rote memorization strategies that do not support deep conceptual understanding or knowledge transfer. The high coefficient of determination ($r^2 = .9082$) observed in this study further underscores the extent to which prerequisite knowledge predicts students' achievement in thermochemistry.

These findings align with earlier research showing that deficiencies in foundational chemistry knowledge significantly hinder learning in advanced topics. Cracolice and Busby (2015) reported that students who enter advanced chemistry instruction without strong conceptual foundations struggle to interpret energy-related concepts and frequently develop persistent misconceptions. Similarly, Tümay (2016) emphasized that learning difficulties in chemistry often originate from weak prior knowledge, which becomes increasingly problematic as content grows more abstract. The present study extends this body of research by quantitatively demonstrating the magnitude of the relationship between prerequisite knowledge and thermochemistry achievement among senior high school students.

The similarity in descriptive statistics between the prerequisite concepts test and thermochemistry achievement scores further reinforces the interconnectedness of these learning domains. The comparable means, standard deviations, and score ranges suggest consistent patterns of performance across both measures. This consistency supports the view that achievement in thermochemistry is not an isolated outcome but rather reflects students' overall conceptual readiness in chemistry. This finding is consistent with Raker and Holme's (2014) assertion that students' ability to engage with complex chemical systems is strongly influenced by their familiarity with foundational concepts.

From an instructional perspective, the findings highlight the importance of ensuring that students possess adequate prerequisite knowledge before introducing thermochemistry. The exceptionally strong relationship observed suggests that strengthening foundational concepts may yield substantial improvements in thermochemistry achievement. Instructional practices such as diagnostic assessment, targeted remediation, and scaffolded learning experiences may be particularly effective in addressing conceptual gaps early. This perspective aligns with Button et al. (2023), who emphasized the importance of instructional approaches that are responsive to students' prior knowledge and reasoning processes.

Additionally, the use of continuous classroom-based assessment to measure thermochemistry achievement offers insight into students' learning over time. The consistency of students' performance across exercises, quizzes, and projects suggests that observed difficulties are likely conceptual rather than merely procedural. Addressing these challenges may require a shift toward instructional strategies that emphasize conceptual understanding, multiple representations, and explicit connections between prerequisite knowledge and thermochemical principles.

Although this study focused on senior high school students, its findings carry important implications for chemistry instruction at the tertiary level. University instructors often assume that students entering higher education possess sufficient foundational chemistry knowledge. However, the results suggest that gaps in prerequisite concepts developed at the secondary level may persist and continue to influence students' performance in more advanced chemistry courses.

Overall, the findings emphasize the pivotal role of prerequisite chemistry knowledge in shaping students' understanding of thermochemistry. By empirically demonstrating the strength of this relationship, the study contributes to the growing body of STEM education research that highlights the importance of curriculum coherence and instruction grounded in strong conceptual foundations. Strengthening students' prerequisite knowledge at earlier stages of learning may therefore be a critical strategy for improving learning outcomes in thermochemistry and other complex areas of chemistry.

CONCLUSIONS

This study investigated the relationship between senior high school students' achievement in prerequisite chemistry concepts and their achievement in thermochemistry. The findings revealed an exceptionally strong positive correlation between students' mastery of foundational chemistry concepts and their performance in thermochemistry, underscoring the critical role of prerequisite knowledge in learning advanced chemistry topics. A substantial proportion of students demonstrated low to moderate achievement in both prerequisite concepts and thermochemistry, indicating persistent conceptual gaps that limit meaningful understanding.

The results affirm the hierarchical and cumulative nature of chemistry learning, where difficulties with foundational concepts—such as atomic structure, chemical bonding, and the particulate nature of matter—directly constrain students' ability to comprehend abstract thermochemical ideas. By quantitatively demonstrating the magnitude of the association between prerequisite knowledge and thermochemistry achievement, this study contributes empirical evidence to chemistry and STEM education research emphasizing the importance of conceptual coherence and instructional continuity in science learning.

Implications for Practice

The findings of this study have important implications for chemistry instruction and curriculum implementation at the senior high school level.

First, the strong association between prerequisite knowledge and thermochemistry achievement highlights the need for diagnostic assessment of students' foundational understanding before introducing thermochemistry. Early identification of conceptual gaps can enable teachers to make informed instructional decisions.

Second, the results suggest that targeted remedial instruction focused on key prerequisite concepts may be essential for supporting students who struggle with advanced chemistry topics. Addressing these gaps may help prevent the accumulation of learning difficulties that negatively affect subsequent achievement.

Third, the findings underscore the importance of curriculum sequencing and alignment, ensuring that prerequisite topics are not only covered but sufficiently mastered before thermochemistry instruction begins. This has implications for curriculum planners and educators responsible for pacing and content emphasis.

Fourth, the findings highlight the need for instructional strategies that explicitly assess and strengthen prerequisite knowledge before introducing thermochemistry. Diagnostic assessments, scaffolded instruction, and conceptual bridging activities may help teachers identify learning gaps and support students' conceptual readiness.

Finally, the study supports the adoption of conceptually oriented instructional approaches that emphasize multiple representations, conceptual explanations, and explicit links between foundational concepts and thermochemical principles. Such approaches may enhance students' ability to integrate prior knowledge with new content.

Implications for Future Research

Future studies could extend this work by employing experimental or longitudinal designs to examine causal relationships between prerequisite knowledge and achievement in thermochemistry. Research involving larger and more diverse samples across different regions would also help improve the generalizability of the findings. Additionally, qualitative investigations into students' reasoning processes could provide deeper insight into how specific prerequisite misconceptions influence learning in thermochemistry.

Limitations of the Study

Despite the strength of the findings, several limitations should be acknowledged. The correlational design of the study does not allow for causal inferences regarding the influence of prerequisite knowledge on thermochemistry achievement. The sample was drawn from selected senior high schools within the Cape Coast Metropolis, which may limit the generalizability of the results to other contexts. In addition, thermochemistry achievement was measured using continuous classroom-based assessments, which, although reflective of authentic learning, may be influenced by variations in instructional practices and assessment conditions across schools.

Additionally, although the PCAT demonstrated acceptable internal consistency (α = .78), it was researcher-developed and not a nationally standardized instrument. Similarly, thermochemistry achievement scores were derived from teacher-developed assessments, which may reflect variations in instructional and assessment practices across schools. These factors should be considered when interpreting the strength of the observed relationship.

AI DISCLOSURE STATEMENT

Artificial intelligence (AI) tools were used during the preparation of this manuscript to assist with language editing, formatting, and general writing support. The authors reviewed, verified, and edited all AI-assisted outputs to ensure accuracy, originality, and compliance with academic standards. The authors take full responsibility for the content of the manuscript, including the integrity of the data, the validity of the analyses, and the accuracy of all references and citations.

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Bios

KENNETH AFEDZI HAYFORD, MPhil, is a PhD student in Science Education and a Chemistry educator with research interests in chemistry education, technology integration in science teaching, and students' conceptual understanding of chemical concepts. His research focuses on improving the teaching and learning of organic chemistry through digital tools such as ChemDraw and guided worksheets, particularly in the drawing and naming of hydrocarbons among senior high school students in Ghana. He is also interested in studying students' conceptual difficulties and alternative conceptions in thermochemistry. Email: kennethhayford24@gmail.com

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