UNIVERSITY OF EDUCATION, WINNEBA

EFFECTS OF PREDICT-OBSERVE-EXPLAIN MODEL-BASED INTERACTIVE TEACHING ON THE NATURE AND QUALITY OF SCIENTIFIC EXPLANATIONS BY PRE-SERVICE TEACHERS

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DOCTOR OF PHILOSOPHY

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DECLARATION

STUDENT'S DECLARATION

I, **Nelly Adjoa Sakyi – Hagan**, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

Signature: …………………………….

Date: …………………………………….

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on the supervision of thesis as laid down by the University of Education, Winneba.

Professor Victor Antwi (Principal Supervisor)

Signature: …………………………

Date: ………………………………

Professor Ruby Hanson (Co-Supervisor)

Signature: …………………………

Date: ………………………………

DEDICATION

To you Emmanuel, and all the children.

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ABSTRACT

This study investigated the effects of the Predict-Observe-Explain (POE) model-based interactive teaching and learning strategy on the nature and quality of scientific explanations by pre-service teachers. Additionally, it aimed at exploring how the pre-service teachers perceived the POE model-based strategy in terms of its impact on their conceptual learning (cognitive), attitudes towards science (behaviour), as well as interests and motivations (emotions) in studying science concepts in Heat and Thermodynamics. An action research approach was adopted with Pre-tests and Post-tests quasi-experimental design on a purposively sampled intact group of 251 Level 100 Integrated Science students of the Department of Integrated Science of the University of Education, Winneba. The Questionnaire on Perceptions of the POE Model-Based Teaching and Learning (QPPOE) was used to obtain the students' perceptions of the strategy. Both quantitative and qualitative methods were used for data collection and analysis to ensure triangulation and increase the credibility and validity of the findings. The findings revealed that prior to the use of the POE model-based teaching strategy, about 61.4% of the pre-service science students' explanations of concepts were mainly descriptive and everyday in nature, thus, being informal and not reflecting the use of formal language of science. The number of participants who provided formal explanations remained consistently low across all 5 Pre-tests on the nature of explanations, with only 6.3 % of participants providing such explanations. However, after the use of the POE model-based teaching and learning strategy as an intervention, the students' explanations to concepts improved, with the majority (86.9%) of the explanations being formal and causal in nature, inculcating experts' language of science. Consequently, the percentage of informal explanations had dropped from about 60% to 12%. Quality of the teachers' explanations also improved after the use of the POE model-based strategy, changing from mainly wrong and partial to sound explanations. This demonstrated a deeper understanding of scientific concepts and accurate reasoning after the intervention. Thus, after the intervention, 89.6% of responses were categorised as sound explanations compared to 16.7% which was recorded before the intervention. The findings from the QPPOE indicated that the students had positive perceptions of the use of POE model-based strategy with improvements in their cognitive, behavioural and emotional aspects in studying the science concepts. The findings further revealed that about 70% of the students had positive perceptions towards the use of the POE model during the study, and again, there was no statistical significant difference between females and males in their perceptions towards the use of the model in the study of the science concepts ($\chi^2 = 0.687$, $p > 0.05$). The study therefore concludes that the POE model-based teaching and learning strategy was an effective approach for improving the nature and quality of the pre-service science teachers' explanations to concepts in science. This study recommends the use of the POE model-based teaching and learning strategy to Science Educators at the various teacher training institutions in the teaching and learning concepts in science. It also contributes to research data and the growing body of knowledge on interactive model teaching and learning strategies in science education, and as well has practical implications for science teacher education programs.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter begins with the background to the study, which focuses on the Predict-Observe-Explain (POE) model, interactive teaching and the importance of learners' scientific explanations. It also highlights the problem statement, the research gap identified and the purpose of the study. The research objectives as well as the research questions and hypotheses guiding this study are also outlined. Furthermore, the chapter discusses the significance and scope of this study, indicating how this study will benefit various stakeholders, and explains the factors limiting and delimiting the study. Finally, the chapter ends with a summary and an indication of how the rest of the chapters of the study are organised.

1.1 Background to the Study

The Predict-Observe-Explain (POE) model of engaging learners, an inquiry-based approach to teaching and learning, has been touted as an efficient teaching strategy for eliciting and promoting discussion of students' science conceptions (Hilario, 2015; Kearney & Treagust, 2001). As the name implies, the POE method of instruction is a teaching strategy that requires learners to carry out tasks in three steps probing understanding. In the first step of the model, learners are required to predict the outcome of an activity, and by so doing commit themselves to a possible reason(s) for their prediction. In the second step, they are made to observe. During the observation, students are expected to study, interact with or engage in an activity, phenomenon or concept. Then final or the third step provides reason-seeking explanations in their effort to explain or reconcile any possible discrepancy between their prediction and their observation. A study by Nalkiran and Karamustafaoglu (2020) revealed that the POE model of teaching and learning does not only determine students' current prior knowledge and their scientific inconsistencies but also helps to eliminate misconceptions. Whether used individually or in collaboration with other students, POE model-based tasks have been useful in helping learners explore and justify their own individual ideas, especially in the prediction and explanation or reasoning stages (Hilario, 2015). Kearney (2004) also indicated that when students are prompted by POE tasks, they are encouraged to justify, articulate and reflect on their own ideas, while engaging in meaningful discussions with their peers. Applying the POE learning model to the teaching and learning process also helps students to think scientifically, participate in scientific problem-solving processes, begin scientific dialogue, provide basis for further scientific exploration and explanation, and improve science learning and performance (Rini et al., 2019). The use of the POE model coupled with active interactive engagement of learners could help elicit positive feedbacks from learners, especially in science classroom (Zacharias, 2005). Similarly, interactive teaching methods tend to involve learners in hands-on activities and encourage them to engage in interactions, which can help them to integrate their experiences and develop a deep understanding of scientific concepts.

Interactive teaching may be described as a means of instruction whereby teachers involve learners in the teaching and learning process through active and regular teacher-learner interaction, learner-learner interaction, use of audio-visuals and hands-on activities. The use of interactive teaching instruction in the teaching and learning process may not only provide learners with concrete experiences, but could also help them to integrate these experiences in understanding scientific concepts. Thus, in the interactive classroom, students are constantly supported and encouraged to be active participants of the teaching and learning process, where understanding and meaning are emphasised, as opposed to mere rote memorisation (Zai et al., 2020).

According to research, learners' construction of explanations which is a way of ascertaining how well they understand a concept mostly develops from engaging them in interactive teaching (Darling-Hammonda et al., 2020; Zacharia & Anderson, 2003; Toa & Gunstone, 1999). Interactive teaching allows learners to directly manipulate initial conditions and immediately see the impact (Antwi, 2013). For more than a decade, authors have documented the potentially positive impact of interactions on learners' instructional approaches, instructional capabilities, development of skills, development of cognitive and metacognitive skills, development of attitudes and development of conceptual understanding (Antwi, 2013; Timperley et al., 2007). A study conducted by Ouahi, Lamri, Hassouni and Al Ibrahmi (2022) indicated that interactive teaching and learning can be a useful solution to improving students' creativity in the science classroom. The integration of interactive teaching into the learning space could help activate multiple scientific process skills such as observing, measuring, predicting, controlling variables, formulating hypotheses and interpreting results in science learners (Ouahi et al., 2022). Acquiring these scientific skills could enable learners explicitly develop metacognition and encourage them to reflect on their own learning; a practice which tend to positively affect classroom motivation and interest.

Studies prove that interactions in the classroom also influence students' problem-solving skills since interactive teaching is an inquiry-based approach to teaching and learning (Attard et al., 2021; Alfieri et al., 2011). The effectiveness of inquiry-based science education cannot be underestimated since it tends to be based on teaching techniques which adopt strategies such as questioning and investigating. By adopting such techniques, the learner placed at the center of the action of their learning, questions themselves and acts in a reasoned manner. Consequently, the learner obtains the ability to explain scientific concepts and communicates to build their learning while being an actor in the whole teaching and learning process (Adofo, 2017).

Scientific explanation could simply be defined as making scientific claims and justifying those claims with appropriate evidence and reasoning. Engaging learners in scientific explanations provide numerous benefits to the learners since science explanations play a key role in an individual's ability to obtain knowledge and understand the world; as well as to learn and communicate effectively scientific phenomena (Giere, 2005). Being able to connect scientific explanations to conceptual understanding makes scientific explanation not only one of the goals of science education, but as some philosophers of science would put it, the very purpose of science itself, and also a means for exposing conceptual understanding (McMillan et al., 2018). Hence, a call to construct a scientific explanation is a call to exhibit the ability to provide both appropriate explanation and the evidence of conceptual understanding (Darling-Hammonda et al., 2020).

According to McNeill and Krajcik (2012), when students are able to develop science explanations, it helps them to learn the science content and also motivates them to want to study science as they realise that learning science is more than just memorising facts. The authors further opined that students' abilities to develop scientific explanations prepare them to become scientifically literate as they develop the skills to read and understand critically the claims of others. They are also able to communicate their own ideas with supporting evidence and reasoning. Thus, students need to be engaged in inquiry-based practice to be able to conduct their own explorations of the world around them as well as in the science classroom.

Pre-service science teachers are considered a major part of every country's educational progress, as they are seen to be tomorrow's educational leaders (Schleicher, 2012). These teachers are required to be well trained in the field of science, expected to have general and specific efficacy demanded by the teaching profession (Numanoğlu & Bayır, 2009) and also, be able to provide the requisite conceptual scientific explanations needed to teach and guide young learners in their study of science. It may be considered common knowledge in the field of the teaching profession that a teacher's conceptual understanding, and hence knowledge of the subject matter (science) affects students' achievement in the subject.

Pre-service science teachers' abilities to develop deeper scientific explanation in science concepts could lead to successful gains in their own learning pathway as students, and in future, as full professional teachers. As student-teachers, the ability to develop deeper scientific explanations would enable them gain a deeper understanding of science concepts, develop the requisite scientific practices and skills, understand the nature of science, develop twenty-first-century problem solving skills, develop twenty-first-century communication skills, acquire listening and constructive-response skills and improve literacy skills (McNeill & Krajcik, 2008). Acquiring these important gains as student-teachers could have a rippling effect on their teaching professions and on their students as well. McNeill and Krajcik (2008) further reiterate that as professional teachers, they would become more attentive to science content, student thinking and understanding, and would be careful to represent concepts in ways that would not unintentionally reinforce or support the development of student misconceptions. Consequently, they would recognise the importance of classroom talk by engaging their students more and also adopt more interactive roles in small groups.

The University of Education, Winneba (UEW), is a public university in Ghana that focuses on teacher education and training. One of the numerous programmes that UEW offers is the Integrated Science Education program, which aims to prepare pre-service students to become competent and effective integrated science teachers at the pre-tertiary levels in Ghana. The program offers courses to equip undergraduate pre-service students with the necessary knowledge and skills to effectively teach science in the classroom. Curriculum for the program is designed to provide a solid foundation in science concepts and theories, as well as practical teaching experience through classroom observation and teaching practice. In addition to classroom instruction, the students have access to science laboratories, science equipment, educational materials and research facilities to enhance their learning experience (Department of Integrated Science Education [DISE], 2021).

Level 100 students in the Integrated Science Education program at the University of Education, Winneba are typically students who have completed their second cycles of education, and are in their first year of study. These pre-service science teachers are beginning their journey to becoming competent, skilled and knowledgeable professional science teachers. As pre-service teachers, they are expected to develop a range of theoretical and practical experiences that will enable them develop the skills and competencies needed to effectively teach science to students at different levels (Schleicher, 2012). However, the common approach to teaching at the various second cycle institutions in Ghana appears to emphasise memorisation of scientific facts and the replication of scientific experiments, and so, many Level 100 students may have been exposed primarily to the traditional didactic approach to science education (Ohlemeier et al., 2012; Davis & Anyan, 2021). This approach tends to rely heavily on textbooks and lectures, and may not provide students with many opportunities to engage in hands-on learning experiences or to develop critical thinking skills.

Previous research has primarily focused on various teaching methods to enhance conceptual understanding and performance in science, but there is limited exploration of the effectiveness of these methods in developing students' abilities to provide sound and scientifically accurate explanations (Kim & Axelrod, 2005; McMaser & Fuchs, 2005; Ryder et al., 2006; Joyce, 2006). The authors revealed some discrepancies in literature regarding the effectiveness of different teaching methods in promoting conceptual understanding and sound scientific explanations. Resolving this conflict is essential for identifying the most impactful strategies for science teaching and learning, and this study focuses on this resolve. While the POE model has been studied in various science disciplines, there is a notable absence of research on its application in the context of Integrated Science Education (Kırılmazkaya & Zengin-Kırbağ, 2015; Hong et al., 2021), particularly at the University of Education, Winneba. This lack of research on the application of the POE model in Integrated Science Education programmes at the University of Education, Winneba, poses a challenge, concerning the training of pre-service science teachers, and hence understanding the effectiveness of this model in this specific context is crucial for curriculum development and improvement. Moreover, the existing studies on the POE model have not included first-year pre-service science teachers at a Ghanaian public university, leaving a gap in understanding how this specific group engages with and benefits from the POE model. Prior studies have not explicitly assessed the effect of the POE model on the nature and quality of scientific explanations of concepts by any group of students. This study seeks to fill this gap by specifically examining the impact of the POE model on the explanatory skills of first-year pre-service science teachers.

The integration of interactive teaching methods in the POE model, in enhancing students' conceptual understanding and scientific explanations of concepts has not been extensively explored. Although many studies applied interactive teaching methods in science teaching and learning (Antwi, 2013; Attard et al., 2021; Alfieri et al., 2011), none of them involved the integration of interactive teaching with the POE model strategy. This study aimed to address this gap by examining how interactive teaching methods in collaboration with the POE model contributed to enhancing students' scientific explanations. Furthermore, while previous research has touched upon the benefits of scientific explanations of learners (McMillan et al., 2018; McNeill & Krajcik, 2012), there is a need to explore the long-term impact of developing deeper scientific explanations on the teaching and learning practices of pre-service science teachers, since understanding this aspect is crucial for preparing future science educators effectively.

The current state of research lacks exploration of potential gender differences in pre-service science teachers' perceptions towards their learning in the classroom (McIlquham, 2021). Investigating such disparities is important for understanding the nuanced experiences and preferences of male and female students in science teaching and learning. Students in teacher education programmes irrespective of gender are expected to have the requisite conceptual understanding needed to impart the right scientific knowledge to learners. Therefore, care of gender equity must be taken at every level of their training to provide sound bases for reducing gender biases and misconceptions in the field of science.

Conflicts exist among researchers about how teaching and learning models such as the POE model helps students to accurately clear their misconceptions and assimilate encountered knowledge into existing schemas (Şenyiğit, 2021). While the use of the POE learning model has been advocated by many researchers (White & Gunstone, 1992; Kearney & Treagust, 2001; Demircioğlu et al., 2017), there have not been sufficient agreements among them about the specific cognitive and metacognitive behaviours and understanding exhibited by students during the learning process. These include how students make inferences, reflect on new information, and integrate it with their existing understanding (Nawaz et al., 2020; Ballantyne & Bain, 1995; Graesser et al., 2010; Graesser & D'Mello, 2012). Delving into students' cognitive challenges and their ability to make sense of new information within the POE model-based framework is of utmost essence, therefore this study employed strategies that enabled pre-service science teachers provide scientific explanations qualitatively.

New developments in this study sought to explicitly support or guide pre-service science teachers in navigating and making sense of the potentially conflicting information encountered during the POE processes and using the same processes to provide scientific explanations of the right nature and quality.

This study, therefore, employed the Predict-Observe-Explain model-based strategy coupled with interactive teaching to determine the effects on the nature and quality of scientific explanations by pre-service science teachers. The study also explored possible gender differences among the students regarding their perceptions of the POE strategy.

1.2 Statement of the Problem

Learners' abilities to provide sound explanations to scientific concepts could be considered an essential feature because it helps to determine the state of their conceptual understanding of scientific phenomena (McNeill & Krajcik, 2008). Level 100 students in the Integrated Science Education program at the University of Education, Winneba, being pre-service teachers, are expected to exhibit conceptual understanding of science concepts, as well as develop sound and accurate scientific explanations. By so doing, they would be able to help their future students better engage with, understand science concepts and provide explanations to the concepts. Over the years, the Researcher's own interactions with the pre-service science teachers, as well as discussions with other Lecturers of the department about the students revealed that the L100 students lacked the ability to provide sound and scientifically accurate explanations to scientific concepts in their study of science. That is, they are not able to sustain formal thought and deep reasoning in providing explanations to scientific concepts, and also, not able to use the formal language of science in the process as expected of them. This situation is a major cause for worry for the Researcher, as well as the other Lecturers; considering the fact that a teachers' explanations of concepts have an impact on classroom practice and ultimately on students' achievement (Schleicher, 2012).

In the past, many studies have been conducted on different teaching methods that seek to engage students to help them gain conceptual understanding of science concepts, in order to provide the right explanations in science teaching and learning (Chenoweth, 2003; Kim & Axelrod, 2005; McMaser & Fuchs, 2005; Ryder et al., 2006; Johnson & Johnson, 2008; Suther, 2009). These teaching methods were found to be inefficient in probing students' reasoning for their science explanations (Lin, 2006; Joyce, 2006). Other studies involving the Predict-Observe-Explain (POE) model have also been conducted in different science disciplines such as chemistry, physics, mathematic and biology, and its impact on learners such as academic achievement, positive attitudes, metacognitive awareness and self-efficacy have been observed (Kırılmazkaya & Zengin-Kırbağ, 2015; Phanphech & Tanitteerapan, 2017; Rini et al., 2018; Hong et al., 2021). Even though such studies were quite exhaustive, they did not specifically assess the effect of the POE model-based teaching and learning method on the nature and quality of students' explanations to concepts in science. Further, compared to these studies on the POE model, none involved the POE model-based strategy in the area of Integrated Science Education. Finally, an analysis of studies involving the POE model-based strategy revealed that first year pre-service science teachers in a Ghanaian public university had not been involved in any study. Thus, very little is known of the use of the POE model-based interactive teaching strategy in the Integrated Science discipline, in a Ghanaian university, and in assessing the nature and quality of pre-service science teachers' explanations to science concepts. This indicates a knowledge gap in research which this study seeks to address.

Hence, in this study, the POE model-based teaching strategy was employed to assess its effect on the nature and quality of first year pre-service science teachers' explanations to concepts in Heat and Thermodynamics, at the Department of Integrated Science Education of the University of Education, Winneba. The students' perceptions of the model in their study of the science concepts were also determined.

1.3 Purpose of the Study

The purpose of the study was to assess the effects of the Predict-Observe-Explain (POE) model-based interactive teaching on the nature and quality of scientific explanations by pre-service science teachers at the Department of Integrated Science Education of the University of Education, Winneba.

1.4 Research Objectives

The objectives of the research were as follows:

1. Determine the nature of the scientific explanations of pre-service teachers to concepts in science before the use of the POE model-based interactive teaching.
2. Ascertain the nature of the scientific explanations of pre-service teachers to concepts in science after the use of the POE model-based interactive teaching.
3. Examine the quality of the scientific explanations of pre-service teachers to concepts in science before the use of the POE model-based interactive teaching.
4. Assess the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching.
5. Establish the perceptions of pre-service teachers towards the use of the POE model-based interactive teaching of concepts in science.
6. Ascertain the differences between females and males in how they perceive the use of the POE model-based interactive teaching of concepts in science.

1.5 Research Questions

The following research questions guided this study:

1. What is the nature of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
2. What is the nature of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
3. What is the quality of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
4. What is the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
5. How do pre-service teachers perceive the use of the POE model-based interactive teaching of concepts in science?
6. What is the difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science?

1.6 Research Hypotheses

To answer research question six (6), the following null and alternative hypotheses were formulated.

- Null hypothesis (H_0: μ=0): There is no statistical significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

- Alternative hypothesis (H_1: $\mu \neq 0$): There is a statistical significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

1.7 Significance of the Study

This research sought to bridge the knowledge gap by the acquisition of data on the Predict-Observe-Explain (POE) model-based teaching and learning strategy in science. The findings of the research would inform policy debate on the POE as a teaching methodology, as well as curriculum development in science education.

The study would provide in-depth knowledge on the nature and quality of the pre-service teachers' explanations to science concepts. This would equip the teachers to use formal language, and also, reason deeply in providing explanations to scientific concepts. Again, the problem solving and critical thinking nature of the POE model-based tasks would help the students to build on their mental capacities, which could help improve on their cognitive structures both as student teachers and as future professional teachers. Furthermore, the results of this study would enhance pre-service teachers' confidence to use the POE model-based interactive strategy to improve on their own learning, scientific attitudes and self-beliefs. This would motivate the pre-service teachers to carefully plan their instruction and employ appropriate teaching techniques, in order to help their future students become more conscious of their own reasoning in their science classrooms.

The interactive nature of the POE model would provide effective and applicable solutions to students' difficulties in explaining scientific concepts. The study would serve as a teaching guide for other pre-service teachers in other institutions in adopting the POE model-based strategy in teaching science concepts. Last but not least, this study would serve as useful information for future research in either the stated or similar areas of study.

1.8 Scope of the Study

This research work investigated the effect of the Predict-Observe-Explain (POE) model-based interactive teaching on the nature and quality of pre-service teachers' explanations to concepts in science. Specifically, the work focused on only Level 100 students of the Department of Integrated Science of the University of Education, Winneba. The study covered the following variables: the effect of the POE model-based interactive teaching on the nature and quality of pre-service teachers' explanations to concepts, the perceptions of the students on the POE model-based interactive teaching, as well as the differences in the perceptions of the female and male students after the use of the model. The study covered only sub-topics selected from the second semester course titled Heat and Thermodynamics, in the 4-year Bachelor of Science in Integrated Science Education programme accredited for study by students of the University of Education, Winneba. The sub-topics included Heat & Temperature, Thermal Expansion, Quantity of Heat, Specific Heat Capacity, Thermal Conduction, Thermal Convection and Thermal Radiation. The choice of the sub-topics was to equip the pre-service science students with the ability to sustain the processes of advancing and building knowledge in order to enhance their ability to construct formal explanations that reflects the formal language of science.

The study was limited by the lack of generalisability of the findings to other institutions or different levels of students due to the engagement of only the specific group of Level 100 Integrated Science students from the University of Education, Winneba. The study was also constrained by time limitations inherent in the academic calendar, thereby impacting the depth and breadth of the intervention and data collection. Data was collected over a period of nine weeks within an academic semester. Lack of resources such as funding, personnel and laboratory materials influenced the scope and execution of the study. Since the study's findings heavily relied on the responses and perceptions of the pre-service science teachers, their biases, misconceptions and/or their desire to present desirable responses might have influenced the results. Finally, the study focused on the impact of the Predict-Observe-Explain (POE) model-based strategy, and while this approach was effective, the exclusivity of this intervention might have limited the exploration of other potentially beneficial strategies.

1.9 Operational Definition of Terms

- Formal language of science - Formal language of science refers to the use of precise, technical and discipline-specific terminology and conventions in explaining scientific concepts. It involves expressing ideas in a manner consistent with accepted scientific discourse, as used by experts in the field of science.
- Scientific accuracy of a concept - Scientific accuracy of a concept is a measure of the correctness of the information presented by pre-service science teachers in giving a scientific explanation. In the context of this study, it involves the extent to which the teachers' responses align with established scientific concepts, principles and theories, reflecting an understanding of the concept under study.
- Depth of scientific reasoning - Depth of scientific reasoning indicates the level of cognitive engagement and critical thinking demonstrated by pre-service science

teachers in providing an explanation. It involves evaluating how well they analyse, interpret and synthesise information to provide coherent and logical responses.

- Nature of an Explanation - The nature of an explanation refers to the categorisation of pre-service science teachers' responses based on the use of formal language of science. It assesses the extent to which explanations align with expert-level scientific discourse.
- Quality of an Explanation - The quality of an explanation is determined by the scientific accuracy and coherence of the pre-service science teachers' responses. It evaluates the depth of scientific reasoning and the degree to which explanations align with scientifically accepted concepts and theories.
- Formal Explanation (FE) - A formal explanation is characterised by pre-service science teachers' responses that entirely agree with those given by experts in the scientific domain. It reflects a high level of conceptual understanding and proficiency in using the formal language of science.
- Causal Explanation (CE) - A causal explanation involves pre-service science teachers providing the cause and/or effect of a physical phenomenon or concept. It is informal in nature and may not necessarily align completely with expert explanations.
- Descriptive Explanation (DE) - Descriptive explanations are explanations that provide the process of a physical phenomenon without specifically identifying causal relationships. They are characterised by a lack of explicit connections between components of the phenomenon or concept.

- Everyday Explanation (EE) - Everyday explanations reflect the creation of situational meanings derived from informal contexts. These explanations are considered the least desirable, as they lack the use of formal language of science.
- Sound Explanation (SE) - Sound explanations involve accurate use of scientific concepts and theories, demonstrating coherent understanding.
- Partial Explanation (PE) - Partial explanations indicate partial knowledge of the phenomena. While some understanding is evident, ideas may not be presented in an integrated or unified way.
- Wrong Explanation (WE): Wrong explanations are inaccurate, confused and contradictory explanations, exhibiting minimal understanding of the phenomena.
- Pre-service science teachers - Pre-service science teachers are individuals who are currently undergoing formal education and training to become teachers, specifically in the field of science education. In this study, pre-service science teachers are participants enrolled in the Integrated Science Education programme at the University of Education, Winneba.
- Level 100 students - Level 100 students refer to participants who are in their first year of undergraduate studies in the context of tertiary education. In this study, Level 100 students are those who are at the first year of their academic programme in the Integrated Science Education programme at the University of Education, Winneba.

1.10 Summary of Chapter One

In this chapter, there was a discussion on the nature and quality of pre-service teachers' explanations to concepts in science. The study sought to determine the effect of the use of an interactive teaching model; the Predict-Observe-Explain (POE) model where the students were at the centre of the teaching and learning process, and were made to give meanings to concepts through their own efforts. From the objectives stipulated to guide the study, six research questions and two research hypotheses emerged. The chapter included the significance of the study to various stakeholders, as well as and the scope within which the study was placed. Finally, the operational definition of terms and a summary ended the chapter.

1.11 Organisation of the Remainder of the Study

The remainder of this study has five chapters. It begins with chapter 2, which is a review of the theoretical perspectives of interactive teaching based on the POE model, is the coverage of this chapter. The underlying learning theories and their consequences for teaching and learning are examined. This chapter also covers related ideas regarding the POE model-based interactive teaching and its implications for science teaching and learning. A review of studies on the POE model of instruction is also included, and finally, a summary of the key ideas covered concluded this chapter. Chapter 3 is a thorough explanation of the methodology employed in this study. The chapter covers research design, population and sample as well as the data collection and data analysis procedures. Ethical consideration and a summary form the last part of this chapter. Chapter 4 of this study presents the results of the study in line with the research questions, through the analysis of the data. Chapter 5 focuses on a thorough discussion of the findings including useful inferences from the findings. The final part of this study is chapter 6, which presents the summary of findings and conclusion to the study. The recommendations and implications of this study are also discussed in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

In this chapter, relevant literature related to this research was reviewed under four main sub-headings: theoretical framework, conceptual framework, review of related literature and empirical studies. The chapter provides a discourse of the main theories that underpin the strategies employed in this research work. Similarly, concepts related to this study were reviewed in relation to the topic. A summary of the main ideas ends this chapter.

2.1 Theoretical Framework of the Study

Jerome Bruner's concept of discovery learning, which is an inquiry-based approach to learning and is also seen as a constructivist-based approach to education, had an impact on the theoretical framework supporting this research (Bruner, 1966). Constructivism is based on the idea that knowledge is not "something" that can simply be transferred by the teacher standing in front of the class to students sitting in their desks, but rather, knowledge is constructed by learners through an active, mental process of development in which the learners are the builders and creators of meaning and knowledge. According to Gray (1997), constructivism draws on the developmental work of Piaget (1977) and Vygotsky (1978).

2.1.1 Bruner's Discovery Learning Theory

Jerome Bruner, an American psychologist, introduced the Discovery Learning theory, in which he felt that the goal of education should be intellectual development, as opposed to rote memorisation of facts. The discovery learning theory encourages learners to build on past experiences and knowledge, use their intuition, imagination and creativity, and search for new information to discover facts, correlations and new truths (Bruner, 1966). It tends to emphasise on the fact that learning does not equal absorbing what was said or read, but actively seeking for answers and solutions. Thus, learners construct their own knowledge (constructivism) for themselves by discovering as opposed to being told about something (Weibell, 2011). Through discovery learning, learners tend to interact with their environment by exploring and manipulating objects, wrestling with questions and controversies or performing experiments to arrive at a solution.

Balim (2009) stated that using the discovery approach to learning is thought of to increase students' successes and inquiry learning skills more than the traditional teaching methods. Mukherjee (2015) also found that in using discovery learning, students were observed to be engaged in a relatively challenging cognitive activity, and thus, could be a useful method in getting students interested and curious in the learning process. The idea is that students are more likely to remember concepts they discover (construct) on their own through active involvement in lessons.

The discovery learning theory is relevant to this research work in that this work made a shift from the traditional method of teaching that tends to make emphasis while teaching, to a more constructivist approach which allowed learners to make their own meaning of the nature of science. The POE model-based interactive teaching engaged learners co-operatively in open ended and exploratory learning environments, where they constructed meaningful knowledge by themselves (Bozkurt, 2017; Shah, 2019; Abiatal & Howard, 2020; Syahrial et al., 2021). For example, the POE learning model facilitated learners' organisation of conceptual understanding and knowledge in a meaningful manner. In the tasks, the Pre-test questions that were given to the learners allowed them to make their own predictions based on their prior knowledge, by writing their explanations to the concepts. This was then followed by active engagement of the learners in series of interactive and co-operative activities, and finally, allowing them to compare their predictions to their observations to reconcile possible discrepancies. In attempting to reconcile any discrepancies between what they predicted and what they observed, meaningful learning was facilitated. Thus emphasising that knowledge is not passively received but built up by the cognising subject (Glassersfeld, 1995).

The use of the POE learning model, thus, reinforced the discovery learning theory since learners were actively involved in all stages of the model. According to Furqani, Feranie and Winarno (2018), the POE learning model is one capable of optimally developing students' thinking since it engages learners in a discovery path to gaining an understanding of concepts. By the use of the POE learning model teachers could possibly assist learners to improving on their understanding of scientific concepts as well as psychomotor domains. By engaging learners through the three stages of the POE learning model, the learner is cognitively psyched to predict a phenomenon, actively get involved in observations or interactions through various engagements, and finally be motivated to explain his or her results or hypothesis. Through these three stages of engagement, the knowledge acquired through discovery learning will be preserved in the learner's memory (Pamungkas et al., 2017; Furqani et al., 2018).

2.1.2 Piaget's Cognitive Development Theory

Piaget's theory of cognitive development is a comprehensive theory about the nature and development of human intelligence, first developed by Jean Piaget. Piaget (1954) was of the opinion that the theory deals with the nature of knowledge itself and how humans come gradually to acquire, construct and use it. Cognitive development is a progressive reorganisation of mental processes as a result of biological maturation and environmental experience. Thus, learners construct an understanding of the world around them, and then experience discrepancies between what they already know and what they discover in their environment (Piaget & Inhelder, 1973). According to Piaget, the cognitive development of learners towards formal thought could be facilitated through three cognitive processes: assimilation, accommodation and equilibration.

Assimilation describes how humans perceive and adapt to new information. It is the process of taking one's environment and new information and fitting it into pre-existing cognitive schemas (Axelrod, 1973). Assimilation may occur when humans are faced with new or unfamiliar information and refer to previously learned information in order to make sense of it. Piaget (1954) opined that when learners assimilate, they perceive new objects and events according to their existing schemata, mental models or cognitive structures. Piaget emphasised the functional quality of assimilation, where learners tend to apply any mental structure that is available to assimilate a new event, and actively seek to use this newly acquired mental structure.

Accommodation, unlike assimilation may be described as the process of taking one's environment and new information, and altering one's pre-existing schemas in order to fit in the new information. In other words humans understand whatever information fits into their established view of the world, schemas; but when information does not fit, a re-examination and adjustment of people's thinking take place in order to accommodate the new information. Piaget (1954) was of the view that accommodation results as learners reframe or modify their existing schemas or mental representations of the external world to fit their new experiences for learning to occur. Hence, as learners exercise existing mental structures in particular environmental situations, accommodation-motivating disequilibrium results, and they construct new mental structures to resolve the disequilibrium (Piaget, 1954). The state of disequilibrium and contradiction arising between the existing schemata and the more sophisticated mode of thought adopted by the new experience therefore, has to be resolved via equilibrium process. Obviously, accommodation appears to influence assimilation, and vice versa. Hence as reality is assimilated, structures are accommodated.

Equilibration refers to the biological drive to produce an optimal state of equilibrium between people's cognitive structures and their environment (Duncan, 1995). Piaget believed that all learners try to strike a balance between assimilation and accommodation, which is achieved through a mechanism called equilibration. As learners progress through the stages of cognitive development, it is important to maintain a balance between applying previous knowledge (assimilation) and changing behaviour to account for new knowledge (accommodation). Equilibration helps explain how learners are able to move from one stage of thought into the next. Thus, in the view of Piaget (1954), students are actively involved in the construction of their own knowledge. It is therefore argued that knowledge is constructed through action and that learners must continually reconstruct their own understanding of phenomena through active reflection and events till they eventually achieve the ultimate.

In this current study, pre-service teachers were required to do pre-preparatory reading of specified topics before actual lessons begun. In doing their pre-reading assignments, there was the possibility of encountering new concepts which they could assimilate according to their existing cognitive structures. Thus, in this first stage of the Predict-Observe-Explain model of teaching, the pre-service teachers were made to go through the assimilation process. During the second stage of the model, learners proceeded through the stage of accommodation, where they had to realign, modify or reframe existing schemas to fit in new ones. At this stage there was the need for re-examination of their pre-conceived ideas. The interactive activities or engagements during the observation stage, afforded the students the opportunity to discover learning on their own, making the process of accommodation seamless. The third stage of the POE model was where the process of equilibration took place. Students had to reconcile any discrepancies between their predictions and their observations and arrive at meaningful conclusions by themselves.

2.1.3 Vygotsky's Social Development Theory

Lev Vygotsky's theory is unique, in that unlike Piaget, he believed that learning could not be separated from social context (Weibell, 2011). Central to Vygotsky's theory is his belief that biological and cultural development do not occur in isolation (McLeod, 2023). He argued that all cognitive function begins as a product of social interactions and that learning was not simply assimilated but a collaborative process. Vygotsky described the difference between what learners can do unaided and what they can achieve "with a little help from their friends" as the Zone of Proximal Development (ZPD) shown in Figure 1.

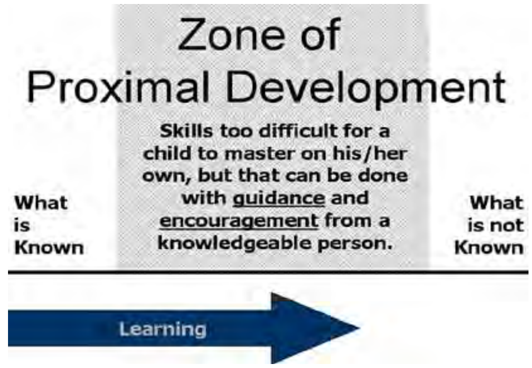


Figure 1: Vygotsky's Zone of Proximal Development

As observed from Figure 1, the ZPD is the distance between a student's ability to perform a task under adult guidance and/or with peer collaboration and the student's ability in solving the problem independently. According to Vygotsky, learning occurred in this zone. To Vygotsky, learning is a continual movement from the current intellectual level to a higher level which more closely approximates the learner's potential. This movement occurs in the so-called "zone of proximal development" as a result of various social interactions; and also, the role of the More Knowledgeable Other (MKO). As they interact through conversations, questioning, explanations and negotiations, meaning is emphasised. Social interaction extends learners' zone of proximal development, which is the difference between their present understanding and the potential to understand more difficult concepts (Vygotsky, 1978).

The implications of Vygotsky's theory to teaching and learning are that teachers and learners ought to play untraditional roles in and out of the classroom as they collaborate with each other. Also key is the presence of the More Knowledgeable Other (MKO), who could be anyone with a better understanding or higher ability level than the learner, with respect to a particular task, process, or concept. The MKO does not necessarily have to be a teacher or older adult, but could also be peers, a younger person, or even computers. Hence, instead of teachers dictating their meaning to learners for memorisation and future recitation, they could rather allow diverse collaborations between learners and the MKO in order to create meaning; and in ways that learners can make their own (McLeod, 2023). Therefore, learning becomes a reciprocal experience for both learners and collaborators. The physical classroom, based on Vygotsky's theory, would provide clustered desks or tables and work space for peer instruction, collaboration, and small group instruction.

In this current study, the POE model-based interactive strategy focused on the connections between the pre-service teachers and the socio-cultural contexts in which they acted and interacted in shared experiences. The model promoted learning contexts in which learners played active roles, especially in the group discussions. Through these social interactions, learners learnt from each other and made meanings on their own. Again, the role of the researcher/lecturer shifted to a facilitator who collaborated with students in order to help facilitate meaningful construction of knowledge. Learning therefore became a reciprocal experience for all.

A key characteristic of the POE learning model is building the critical thinking skills of students (Nalkiran & Karamustafaoglu, 2020), which is also a fundamental feature of the social constructivist theory propounded by Lev Vygotsky (1978). Thus, through this research work, the use of the POE model-based interactive teaching provided an ideal platform in engaging the pre-service teachers through active teaching and learning path.

This model of learning promoted students' conceptual changes by actively confronting the students' prior knowledge and encouraging knowledge application as well as construction (Zhao et al., 2021).

Constructivism as an epistemology, a learning or meaning-making theory, offers an explanation of the nature of knowledge and how human beings learn. That is, the real understanding is only constructed based on learners' previous experience and background knowledge (Ültanır, 2012). Hence, individuals tend to create or construct their own new understandings or knowledge through the interaction of what they already believe and the ideas, events, and activities with which they come into contact. In the constructivism approach, the teacher becomes a guide, facilitator, and co-explorer who encourage learners to question, challenge and formulate their own ideas, opinions and conclusions (Ciot, 2009; Ültanır, 2012).

2.2 Conceptual Framework of the Study

Based on the theoretical framework of the study, and with the assumption that teaching strategies that involve students' active cooperation could lead to worthwhile learning, the conceptual framework of the study was developed. The main idea was that the researcher played key roles in planning and facilitating learning by employing interactive teaching strategies while applying the POE model in the teaching and learning process. This approach prompted learners to take responsibility for their learning, emphasised high-level thinking, focused on intrinsic rather than extrinsic motivation and helped them to remember important information (Bruner, 1966).

The key ideas which informed the approach to the study and their interrelatedness underlined the conceptual framework of the study. This is diagrammatically presented as Figure 2.

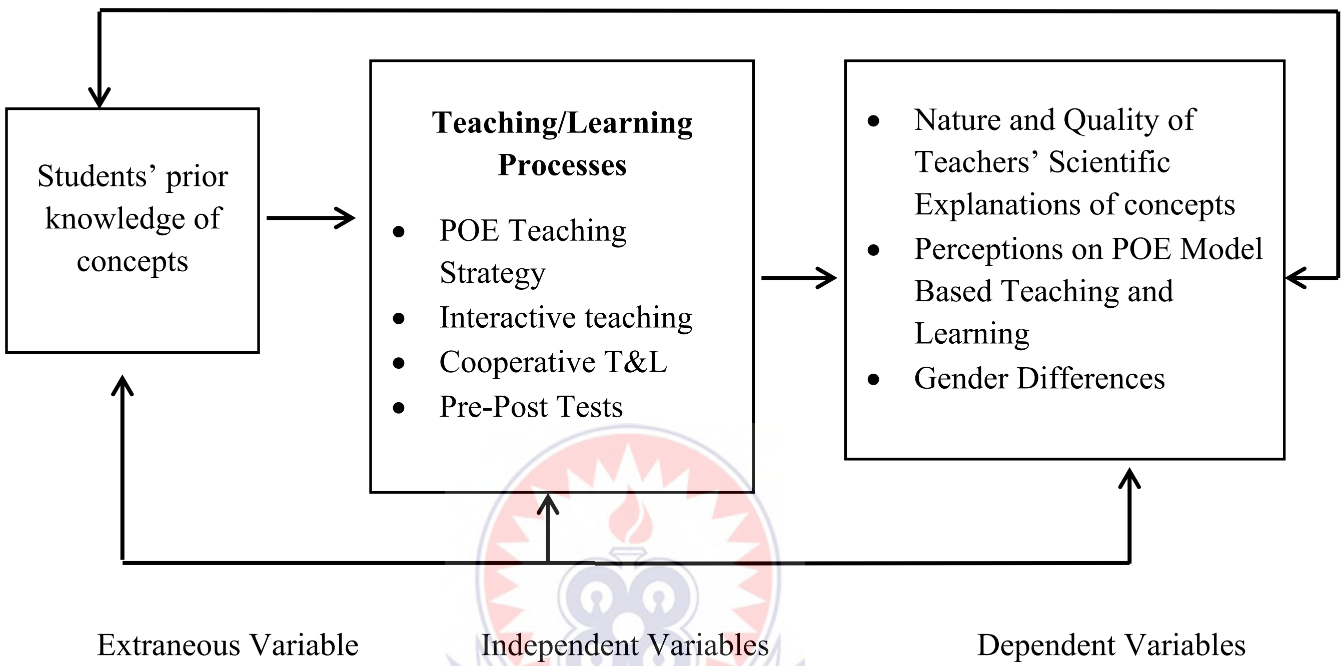


Figure 2: The Conceptual Framework of the Study

2.3 Review of Related Literature

2.3.1 Studies on the Predict-Observe-Explain (POE) Strategy/Model

The Predict-Observe-Explain (POE) strategy, originally known as the Demonstrate-Observe-Explain (DOE) was first used by Champagne, Klopfer and Anderson (1979) to assess the thinking skills of first year physics students at the University of Pittsburg in 1979. The DOE dealt with real-world situations or experiences, and involved the processes of formulating a question for predicting the results of situation/experience, observing the effect of changes to the situation or experience and explaining the results obtained.

According to the authors, the use of the DOE strategy helped in reducing the quantity of verbal descriptions and allowed the use of more open-ended questions, and this provided enough data to help make inferences about learners' conceptual understanding. However, White and Gunstone (1992) redesigned the Demonstrate-Observe-Explain (DOE) strategy and developed the Predict-Observe-Explain (POE) strategy.

In the POE model-based strategy, learners must first predict the outcome of an event, interact with or study an activity and then reconcile contradictions between what they predicted and what they observed. The POE strategy may be taught in science classrooms or even laboratories, and allows learners to connect scientific material to natural events they encounter in their daily lives. This strategy may thus be considered as one of the strategies that teachers could employ in order for learning to occur permanently in the minds of their students. The Predict-Observe-Explain (POE) model-based strategy of teaching and learning adopts an instructional procedure whereby learners are engaged in making predictions for an event, then observing, that is, interacting or studying or demonstrating an activity, and are required to compare what they observed to what they predicted, in order to monitor or evaluate their own learning with the ultimate expectation of enhancing their conceptual understanding of scientific knowledge (Nalkiran & Karamustafaoglu, 2020). Hence, this strategy has the potential of linking learners' prior or existing ideas and understanding about scientific concepts to the actual ideas, meanings or imports of these concepts. In effect, POE stimulates learners' pre-existing knowledge, leaves dispute resolution to the learner, and ensures that techniques or procedures are followed thoroughly without skipping phases (Kearney, 2004).

Further, the POE strategy enables students to build self-confidence, take responsibility in individual and group work, be accountable for their own learning, articulate themselves well, be motivated, make predictions and explain same during the process of learning, and be proactive by encouraging them to find answers. This strategy promotes positive attitudes (Akgün & Deryakulu, 2007; Arsy et al., 2019; Hong et al., 2021). The use of the POE strategy in teaching and learning has been supported by many studies (Coştu, Ayas, & Niaz, 2012; Phanphech & Tanitteerapan, 2017; Rini et al., 2018; Erdem et al., 2022), who have all indicated in one way or the other that the POE strategy allows learners to explore concepts and generate or probe investigation. Further, this strategy also allows learners to express their understanding by explanations, and thus, experience the scientific ideas behind the scientific activities to satisfy their curiosity. Hence, the POE teaching and learning strategy emphasises on learners' explanations to concepts.

According to Burçin (2013), the Predict-Observe-Explain (POE) teaching and learning strategy creates an opportunity for learners to write down their predictions before engaging in an activity; this is then followed by the actual engagement in an activity in which learners observe their predictions and ascertain whether or not their predictions were correct or incorrect. Therefore, this learning strategy explores the initial conceptual understanding of the learners and helps them to determine if these understandings are right or wrong. This provides an opportunity for the learners to play active roles in their own learning processes. Again, the POE strategy refers to a constructivist strategy, in which the student will build knowledge in his own mind based on the direct experience encountered during the learning process (Kearney & Young, 2011; Burçin, 2013). Through POE, learners may develop and effectively articulate their knowledge by reasoning between what they have learned previously and new information they have received afterwards. This method is especially effective in subjects focused on experimentation and observation, such as science (Bilen, 2009). POE enhances student engagement in scientific classes, group or individual investigation, self-confidence, and expression (Vadapally, 2014; Kırılmazkaya & Zengin-Kırbağ, 2015). The strategy also helps move learners from the role of passive observers and involves them throughout the learning process, thereby, allowing them learn about their own understandings and knowledge while also appreciating that scientific knowledge is tentative (Gungor, 2016).

According to Hilario (2015), POE is one of the efficient strategies that help to create learner discussions about the concepts of science. This learning strategy involves learners in predicting phenomena, making observations through cognitive and/or verbal engagements, and finally explaining the results of their outcomes. Hilario (2015) further illustrates the step-by-step approach to using the Predict-Observe-Explain (POE) model-based teaching and learning strategy in lessons. The three-step approach is enumerated below:

Prediction

POE begins with prediction. At this stage learners are provided all the background information or knowledge they need to know about the concepts to be studied and are required to make predictions about these concepts. This activates the learners' existing knowledge, highlights the subject and reveals familiar concepts (White & Gunstone, 1992). An important aspect about this stage is that learners need to write these predictions, in order to be able to make a decision about it later. In this study, the pre-service teachers were made to write a Pre-test as a way of making their predictions about the concepts. This test was based on a pre-reading assignment given prior to the lesson.

Observation

After writing down their predictions, learners go through the second stage of the POE strategy, which is observation. In this phase, learners observe, that is, study, engage in or interact with the activities to be learned. Therefore, learners tend to either watch an event/experiment, or make a presentation, while recording the outcome of the engagement. These observations could be made individually or in groups with the aim of ascertaining whether their predictions were right or wrong.

The observation stage in this study involved the active engagements of the participants using various interactive lessons such as power point presentations embedded with videos, texts and simulations; as well as group presentations and many more. The pre-service teachers mostly collaborated in groups and had discussions on the concepts during lessons. There were many verbal discourses where the participants shared ideas, knowledge and skills.

Explanation

Explaining is the last stage of POE. In this stage, learners become aware of their contradictions by comparing their predictions and observations (Kearney, 2004). This is where learners who made wrong predictions had to face the internal assumptions that led them astray. However, instead of informing learners directly, teachers need to guide them to explain the conflicting situations between their predictions and observations. In comparison to the other two stages, this stage is considered to be difficult for learners.

During this stage, learners could discuss the contradictions they found among themselves or in small groups. Teachers at this stage may accept all ideas presents and support learners in developing different perspectives without judging them. Learners in this level, unlike those at earlier stages, need to be actively encouraged to express themselves effectively and given ample opportunity to do so (Dial et al., 2009).

The third stage was carried out in this study through a Post-test, where the learners had to answer questions similar to the Pre-test questions. The contradictions between their previous answers to the Pre-tests and the current answers could be resolved. Class discussions conducted after the tests proved that participants had made corrections to their predictions in most cases.

In conclusion, learning is considered a personal and unique experience that is different for each person (Cicognani, 2011). Thus, in this study, the Predict-Observe-Explain (POE) was used as an instructional strategy, where learners worked in small groups to make predictions about the concepts, made observations through active participations/interactions, and then compared their observations with their predictions. These allowed them to keep track of their learning activities and enabled them evaluate how well they worked; which helped improved their understanding of the scientific concepts.

2.3.2 Other Strategies/Models of Teaching and Learning

Different models of teaching and learning have been developed by different researchers and for different purposes. A teaching and learning model could simply be described as a teacher's method of teaching or philosophy of teaching and learning underlying the teaching and learning process. Maheshwari (2013) defined a teaching and learning model as one in which an experienced teacher highly focused on achieving a learning objective or behaviour demonstrates particular patterns through which the learner learns by imitation. According to Bruce, Marsha and Calhoun (2011), a model of teaching is described as a plan or pattern that can be used to shape curricula, to design instructional materials and to guide instruction in the classroom and other settings. Hence, a model involves a process to think about and present instruction in which facts are organised, classified and interpreted properly by learners. The process also includes providing particular learning environmental situations which allow learners to interact in such a way that specific changes occur in their behaviour (Bruce et al., 2011). Therefore, a teaching and learning model is useful in designing instructional activities and environmental facilities, as well as carrying out these activities, and finally, achieving learning outcomes or objectives (Maheshwari, 2013).

To enable effective teaching and learning, teachers tend to integrate different models of teaching depending on the learners' learning needs as well as their learning styles. While some models centre on delivery by the teacher, others are developed as the learners respond to various tasks where they are considered partners in the teaching and learning process (Bruce et al., 2009). The kind of model used is based on the criteria enumerated below, according to Bruce, Calhoun, and Hopkins (2009):

• Specification of Environment – determines in precise terms the environmental factors that should be present for evaluating a learner's response.

• Operational specification – refers to the system that enables a learner's response and engagement with the environment.

• Specification of Performance Criteria: outlines the performance criteria that the learner will accept and the behavioural outcome that they will exhibit after completing particular instructional sequences outlined in the teaching model.

• Defining the learning result – describes what the learner will do after completing a set of instructions.

Reeder (2022), identified some basic teaching and learning models, and gave brief descriptions of them based on the specifications above. These are direct instruction, lecture, cooperative learning, inquiry-based learning, seminar and project-based learning.

2.3.3 Direct Instruction Model

In the direct instruction teaching and learning model, the teacher solely takes charge of presenting the lesson and all other relevant information to learners through a presentation. After presenting the material, the teacher guides the learner to practice has been learnt, after which the learner is asked to practice what they have learnt independently by means of homework or an in-class activity. Finally, the teacher evaluates the lesson to ascertain if the learner has mastered the lesson objectives.

The direct instruction model was developed in the 1960s at the University of Illinois at Champaign-Urbana by Engelmann and colleagues. The initial application of the approach was called as Direct Instruction System for Teaching and Remediation (DISTAR) and comprised of reading, language, and mathematics-focused programs (Magliaro et al., 2005). Direct instruction is one of the most widely used methods of teaching, and it begins with the “clear and systematic presentation of knowledge” with the goal of helping students to develop background knowledge so that they may apply and link it to new knowledge

(Kim & Axelrod, 2005). The proponents of direct instruction advocate that direct instruction is a systematic approach to teaching in which the teacher is very explicit about what students are to learn, the language of instruction is very clear, allows teachers the opportunity to monitor their students while teaching and provides constructive feedback (Dean Jr. & Kuhn, 2006). Unlike rote instruction, which compels pupils to memorize answers and repeat them in a rote-like manner, direct instruction scaffolds instruction to match the needs of each individual learner (Kim & Axelrod, 2005; The Education Hub, 2017). However, this mode of teaching has also been criticised for being very rigid, providing little room for adjustment. Further, it restricts the use of active learning strategies such as workshops, dialogues, and case studies (Chenoweth, 2003). According to Ryder, Burton, and Silberg (2006) as cited by Cohen (2008), direct teaching methodologies can be linked to three principles: language is segmented into components that are taught separately; learning is controlled by the instructor; and students have little input. Other studies opine that direct instruction is performed in an authoritarian, manipulative, and bureaucratic manner and is derogatorily described as “dehumanising”, “robotic” and “rigid” (Garza, 2003).

2.3.4 Lecture Model

The lecture method often used in higher education environments such as colleges and university classrooms centres on the teacher verbally presenting information and examples, sometimes along with visual presentations to learners. Thus, active interaction with learners is limited, and typically, not much emphasis is placed on practice and putting the information to practical use except for when the student has to recite the information on a test (Reeder, 2022).

Kaur (2011) describes the lecture method as the most comprehensively used pedagogical method within educational institutions at all levels, which involves instructors imparting information to students in terms of lesson plans and academic concepts within the classroom settings. Some researchers described it as "inheritance knowledge or accept knowledge" with the teacher as the centre, the classroom as the centre and also books as the centre of the teaching and learning process (Shen Wen-jie, 2002; Chen Tan, 2004).

Research conducted by Wang, Zhao and Gao (2013), in which they did an analysis of the traditional lecture method combined with the seminar teaching method in graduate education, revealed that even though the lecture teaching method is touted as beneficial to teaching and learning because it gives full play to teachers' roles as leaders and enables learners to obtain more knowledge, this could also make learners lose the learning initiative and creativity at the same time (Lin, 2006).

2.3.5 Cooperative Learning Model

Cooperative learning is another method that is sometimes used. This learning method involves students working together to accomplish shared goals. With this teaching model, there is the sense of interdependence that motivates group members to help and support each other (Reeder, 2022). Hence, the students work in a group setting where each member has a different task or role, but in the end, come up with a common achievement. When students work cooperatively they learn to listen to what others have to say, give and receive help, reconcile differences, and resolve problems democratically. All students have to work together to come up with the answer or to create the products or project that is required of them. Often, after all groups have finished, each group will be required to present its findings in front of the other groups and the teacher. This method tends to work well in all subject areas, since the premise of cooperative learning is that knowledge is a social construct. In cooperative learning, groups of students come together to solve an issue, finish a task, or develop a project. It is predicated on the notion that conversing among participants while learning is a natural social act and so talk is the medium through which learning takes place. The finest learning occurs when the learner is fully engaged in the activity.

According to studies by Johnson and Johnson (2008) and Suther (2009), students who work in small groups tend to learn more of what is taught and retain it longer than when the same content is provided in other instructional styles, regardless of the subject matter.

Cooperative learning is a methodology that employs a variety of learning activities to improve students' understanding of a subject by using a structured approach which involves a series of steps, requiring students to create, analyse and apply concepts (McMaser & Fuchs, 2005).

Cooperative learning utilises ideas of Vygotsky, Piaget, and Kohlberg, in that both the individual and the social setting are active dynamics in the learning process as students attempt to imitate real-life learning (Palmer et al., 2010). By combining teamwork and individual accountability, students work toward acquiring both knowledge and social skills. It is a teaching strategy which allows students to work together in small groups with individuals of various talents, abilities and backgrounds to accomplish a common goal. Each team member is accountable for mastering the subject matter and assisting the other team members in their learning (Johnson & Johnson, 2008). Students work until each group member successfully understands and completes the assignment, thus creating an "atmosphere of achievement". As a result, they frame new concepts by basing their conclusions on prior knowledge. This process results in a deeper understanding of the material and more potential to retain the material (McMaser & Fuchs, 2005).

The role the teacher plays in establishing cooperative learning in the classroom is critically important for its success. This involves being aware of how to structure cooperative learning in groups, including their size and composition the type of task set; expectations for student behaviour; individual and group responsibilities; and the teacher's role in monitoring both the process and the outcomes of the group experience (Palmer et al., 2010).

A useful strategy that can help students create knowledge in the twenty-first century is the Predict-Observe-Explain (POE) teaching strategy (Hilario, 2015; Scardamalia, 2015). According to Scardamalia, a key concern in the subject of cooperative learning is knowledge acquisition, which can lead to the development or modification of useful knowledge, and result in personal learning. In order to promote effective learning, the POE instructional technique could be incorporated into cooperative teaching and learning activities. As a result, teaching methods based on POE models may be useful in meeting the 21st century's increasing educational expectations. Research indicates that a number of studies have looked into the efficiency of the POE teaching strategy in acquiring cooperative knowledge building (Tao & Gunstone, 1999; Bajar-Sales et al., 2015; Teerasong et al., 2016).

According to Chris (2016), using a cooperative learning technique and a POE model together could enhance the advantages by promoting knowledge building. This was confirmed by Karamustafaoğlu and Mamlok-Naaman (2015) as well as Stoyanova and Kommers (2016), who were able to observe that the POE technique employed in cooperative teaching and learning facilitates knowledge building effortlessly. In this study, the POE model-based strategy was incorporated into an interactive teaching cooperative learning environment because research has shown that cooperative learning can facilitate the exchange of information in a group, clarify the viewpoints of individual group members, and encourage participation in the process (Gao, 2012). When students review and reflect on their learning processes together, they can pick up strategies and methods from one another.

2.3.6 Inquiry-Based Learning Model

Inquiry could be defined as the process of finding answers, information, or knowledge through questioning. Inquiry tends to continue throughout life even if careful thoughts are not given to the procedure. For instance, children learn through asking, babies look at faces, grab items, place them in their mouths, and turn toward noises from birth. Thus, inquiry-based learning starts with using the five senses to obtain data (Exline, 2004). According to Reeder (2022), inquiry-based learning is a teaching model that works especially well in mathematics and science classes. In inquiry-based learning, the teacher presents a problem or a puzzle which students must solve based on their prior information or prior knowledge learned. This method of teaching and learning tends to promote individual or group learning, where learners create a hypothesis using available data, collect relevant information and draw conclusions, which they might present to their colleagues.

In a recent study on the inquiry-based method of instruction, Gholam (2019) posits that to ensure that students become well equipped with the necessary tools to face the demands and expectations of the future; teachers need to use clear instructional practices such as inquiry-based learning. Inquiry-based learning promotes critical thinking, reflection, questioning, collaboration, communication, and research among learners. Inquiry-based learning is an instructional strategy that brings teaching and learning into alignment with the student and the skills needed for future success (Marks, 2013).

The inquiry-based learning which is a student-centered instructional approach makes use of meaningful tasks such as cases, projects, and research to situate learning (Avsec & Kocijancic, 2016). During the process, students are expected to work collaboratively to identify how to solve problems, gain useful research skills, and build each other's capacities (Avsec et al., 2014). This method of instruction tends to engage learners in the learning process and helps them to make sense of the world around them. Alfieri, Brooks, Aldrich and Tenenbaum, (2011) refers to the benefits of inquiry-based learning in the classroom, and asserts that, "allowing students to interact with materials or models, manipulate variables, explore phenomena, and attempt to apply principles affords them the opportunities to notice patterns, discover their underlying causalities, and learn in ways that are seemingly more robust". Therefore, adopting inquiry-based learning actively engages students in the learning process, maximises learning and presents learners with authentic and engaging tasks that are highly motivating.

The Predict-Observe-Explain (POE) model of teaching fits into the inquiry-based method of instruction, in that, this model the prediction stage entails the teacher providing all pertinent background information regarding the problem, so that learners can construct a realistic prediction. The observation stage requires learners' attentive participation and active engagement. Finally, following the observation, the teacher facilitates a conversation in which learners strive to comprehend their erroneous initial assumptions or theories and create new hypotheses that better reflect the observed reality. Depending on the topic and any additional materials that the teacher provides at this stage, the teacher may have little to do other than guide the general discussion of students as they develop their new understanding. Sometimes, teachers may need to help learners articulate their initial misconceptions and then guide them piece together a new theory by drawing their attention to key observations.

POE can be conducted by individual students, but it is frequently most effective in group settings when small groups discuss their ideas. This tends to produce a variety of thoughts that may be compared, rather than a single idea, and if there are several ideas, students must exert effort to explain and defend their opinions. Obviously, for such group work to be effective, the students must have the skills of good listening, turn taking, and reasoning, which are often acquired with the assistance of the instructor over time.

2.3.7 Scientific Explanations and Understanding of Concepts

Students' explanations of natural events have traditionally been used to test how well they understand the topic and to plan lessons (Champagne et al., 1985; White & Gunstone, 1992). Thus, the generation of scientific explanations tends to be an important learning goal in the teaching and learning of science. However, there seem to be no clear criteria for scientific explanation of natural phenomena in science education. Learners' abilities to provide the right scientific explanations to concepts at various levels of education has been an issue of concern for many decades (Ruben, 1990), as there has not been a single or commonly accepted definition of explanation in research. According to Ruben, this lack of agreement stems from the fact that there are no generally accepted rules of what an explanation is. Further, Gilbert, Boulter, and Rutherford, (1998a) opined that differences or discrepancies in providing explanations occur because explanations "vary as a function of the individual experiences of the learner, and also the perceived expectations of teachers or those asking the questions".

Research has indicated that science explanations provide a window into a person's thinking and a way to help learners understand scientific phenomena (Zuzovsky & Tamir, 1999; Treagust & Harrison, 2000). Furthermore, science explanations are important for people who want to learn about and understand the world, as well as for people who want to learn about, understand and explain scientific phenomena. Hence, explanation is an important part of understanding. As revealed by Lampinen, Abbott and McClelland (2020), scientific explanations must be able to make clear something that was not clear before, or increase the understanding of concepts. Previous researchers had also expressed that scientific explanation is the whole point of science (Hill, 1986; Kourany, 1987). Therefore, when explanations are linked to understanding, they become not only one of the goals of science education, but also a way to show understanding (Zuzovsky & Tamir, 1999; Southerland et al., 2001). Thus, a call to construct a scientific explanation is a call to exhibit the ability to provide both appropriate explanation and the evidence of conceptual understanding (Darling-Hammonda et al., 2020).

2.3.8 Types of Scientific Explanations

Since explanations are not only of something but for someone, the range of possible explanations that could be provided to a given question depends on the knowledge available to the explainer and the knowledge assumed to be available to the explainee (McEwan & Bull, 1991). According to Achinstein's Law and Explanation (Achinstein, 1971), the general model that describes *an explanation (E)* depends on *who (A)* explains, *what (q),* to *whom (S)*. Thus, *E* may be a fact, a sentence or anything else that a person, *S* will find "illuminating". Therefore, the criteria for a satisfactory *explanation, E* require that *S* understands *q*; and also depend on the knowledge and concerns of *S* such as relevance, correctness and depth. This model can be represented in short as E=f (A, q, S). The explanatory methods used in different fields of empirical sciences tend to differ fundamentally, and so, the essential components and structure required to construct a scientific explanation may also vary, for example, physics, biology, etc. (Gilbert et al., 1998a; Treagust & Harrison, 2000). As a result, different types of explanations may be found in the scientific and science education literature.

Deductive-Nomological (D-N) Model of Explanation

The Deductive-Nomological (D-N) model of explanation is one of the typical explanation structures that stand out in the science education literature. It proposes that scientific explanation requires the explanation to be not only psychologically satisfactory or merely familiar, but that the phenomenon (q) can be accounted for by the application of relevant scientific knowledge (Hempel & Oppenheim, 1988). The model, first described by Hempel (1965) and later by Hempel and Oppenheim (1988), posits that a scientific explanation is made up of two types of sentences: *explanan* and *explanandum*. The explanans are specific antecedent conditions and/or general laws that can be used to derive the explanandum (the phenomenon to be explained). According to Zuzovsky and Tamir (1999), the construction of a D-N explanation must satisfy certain logical and empirical conditions: its explanandum must be a logical consequence of the explanans, the explanans must contain general laws, which must be capable, at least in principle, of being tested by experiment or observation, and the sentences constituting it must be true, that is, supported by available evidence. Research has proven that when "why" questions are asked, the D-N explanation is usually elicited, and also "why" questions require the identification and application of rules or principles to explain a specific physical phenomenon (Zuzovsky & Tamir, 1999).

Reason-Seeking (Predict-Explain) Model of Explanation

Another type of question is the "predict and explain your answer" type. In this type of questioning, the usual requirement for a D-N explanation is replaced by a reason-seeking type of explanation (Zuzovsky & Tamir, 1999: Zacharias, 2005). Reason-seeking explanations, according to Hempel (1965), are rational arguments. Their construction necessitates consideration of underlying reasons, which may include assumed outcomes, beliefs about the efficacy of alternative means of achieving these outcomes, and a critical evaluation of the chosen means (Hempel, 1965). The POE model consists of three distinct steps. Participants must provide reason-seeking explanations in the first step in order to explain the reasoning behind their prediction. The participants must observe/study the phenomenon in the second step, and in the third step, they must provide a combination of D-N and reason-seeking explanations in order to explain/reconcile any possible discrepancy between their prediction and their observation.

This research work was concerned with only the particular type of explanation where *q* is of the form *why (or how) some phenomenon happens* in a context of inquiry in natural science. Therefore in this study, only the deductive-nomological (D-N) and reason-seeking explanations were elaborated on, because they are most relevant to the conceptual-based science curriculum and, in particular, the POE model-based strategy that was employed (Zacharias, 2005).

2.3.9 Assessing Scientific Explanations

The process of constructing any form of scientific explanation (e.g., D-N explanations, reason-seeking explanations) comprises knowledge acquisition and knowledge advancement (Bereiter, 2002). According to De Vries, Van den Hooff and De Ridder (2006), individuals must externalise their information while simultaneously explaining, organising and building/restructuring it in order to produce an explanation. The same study indicates that when learners detect gaps in their own explanations, they employ a strategy to improve the information reflected in their explanations. This process includes identifying gaps between prior and taught knowledge, acknowledging the need for new/additional knowledge, and continuing the quest for new scientific explanations.

The scientific explanations assessed in this study were examined to determine their nature and quality. The nature of an explanation was determined by the participants' ability to construct scientific explanations using formal language of science, while the quality of an explanation was determined by focusing on in-depth advancement or depth of reasoning in providing a scientifically accurate explanation.

Assessing the Nature of Scientific Explanations

Science education has studied individuals' views on science for a long time, but few studies were found that looked at the nature and structure of explanations given by people from different backgrounds and in different settings (Gelman & Baillargeon, 1983; Tamir & Zohar, 1991; Hammer & Elby, 2002).

Gelman and Baillargeon (1983) looked at how young children's knowledge of physics changes over time. He also looked at how 32 children aged 3-9 explained why gears got stuck. There were three stages of development, which involved *using the object's function as an explanation*, *using connections as explanations*, and *using mechanistic explanations*. Tamir and Zohar (1991) found that high school biology students used *teleological*, *anthropomorphic, functional* and *genetic* reasoning to explain things about plants and animals. Hammer and Elby's (2002) study investigated how people without formal training in physics explain and understand physical phenomena. They found that non-physicists, such as elementary school students and adults without formal physics training, tended to use a wide range of explanations that were often *complex, verbal*, and rooted in *everyday experience*. Physical science teachers, on the other hand, tended to use a *single model*, often described in terms of *deductive reasoning* and *formula-driven* calculations. High school physics teachers and graduate students fell somewhere in between, with some relying on the single-model approach and others using more complex and varied explanations. Another group of researchers put college students' explanations of physics into three groups, as *intuitive, formula-driven*, and *hierarchical* (Touger et al., 1995).

Kaartinen and Kumpulainen (2002) developed a criterion that was used to categorise participants' explanations based on the use of formal language in science, that is, *formal explanation (FE), causal explanation (CE), descriptive explanation (DE)* and *everyday explanation (EE)*. They described the category of formal explanation (FE) as explanation reflecting formal scientific terminology and methods. Further, an explanation in this category contains language and structure that are consistent with what scientists know. In the causal explanation (CE) category, informal language is used to describe the cause and/or effect of physical phenomena. These explanations are less formal than formal explanations and are not necessarily consistent with the explanations of experts.

Explanations that merely explain the procedure of a physical phenomenon, without establishing firm causal connections, fall under the heading of descriptive explanations (DE). The category of everyday explanations (EE) illustrates the emergence of situational or practical meanings from informal contexts.

This study adopted the Kaartinen and Kumpulainen (2002) scale for categorising the nature of scientific explanations. There was the need to determine if the participants could improve on their explanations to become more explanatory or detailed, reflecting cause-effect reasoning and formal reasoning, rather than using only their everyday understanding of the phenomena. Due to their peculiar status as pre-service science teachers, the participants' possible transition from informal to formal explanations and from descriptive to causal reasoning was especially important to investigate. This is because science teaching entails communicating scientific knowledge to learners, whether scientists or non-scientists, using formal explanations (Treagust & Harrison, 2000).

Assessing the Quality of Scientific Explanations

One of the factors determining the quality of a given explanation may be the extent to which the learner has progressed in the search for new explanatory scientific knowledge during the course of his or her inquiry; an indication that the learner's knowledge might have become more multifaceted and articulated as a result of adopting explanatory scientific concepts and theories (Zacharias, 2005).

The depth of a learners’ explanation, referred to as the degree of deepening/deep reasoning, also called progressive deepening, is determined by the extent to which it goes beyond a mere description of objects and relationships, and strives to establish an interpretive mechanism behind the phenomena being explained (Hakkarainen, 2004). Nevertheless, the quality of an explanation is not only defined by its reasoning depth, but also by its level of accuracy as a scientifically acknowledged explanation. The scientific accuracy of an explanation is determined by the degree to which the description of the relevant items, their relationships, and the underlying mechanism corresponds to existing scientific knowledge. Thus, an explanation should be more complete and well-thought-out, using scientifically valid ideas and theories to explain the scientific phenomenon being studied (Treagust & Harrison, 2000). In evaluating the quality of an explanation, it is essential to evaluate both characteristics, as depth does not necessarily guarantee scientific accuracy, and vice versa. Numerous studies conducted on learners' conceptual understanding and alternative ideas have revealed that, an individual's depth of explanation may progress significantly despite being scientifically inaccurate (Sneider & Ohadi, 1998; Tytler, 1998). On the other side, there are instances in which learners give ideas that initially appear to be accurate or valid, but when they attempt to explain them further; it is revealed that their explanations are inconsistent with scientifically accepted concepts and theories (Vosniadou & Brewer, 1992; Vosniadou, 1994). Thus, learners may hold alternative frameworks or mental models that are inconsistent with scientifically accepted concepts and theories, and that these alternative frameworks may persist even in the face of contradictory evidence. Consequently, a scientific explanation must be applicable to a phenomenon and accurate in the context of the phenomenon.

In this study, the pre-service science teachers' depths of scientific reasoning and scientific accuracy were evaluated as they provided explanations for various scientific ideas. Both factors were important in determining the quality of an explanation. The researcher developed a scoring criterion adopted from a similar one used by Costu, Ayas, Niaz, Unal and Calik (2007) for assessing these factors in a scientific explanation. An explanation was considered to be sound or legitimate (of good quality) only when scientific accuracy was combined with the corresponding degree of deepening. A legitimate explanation should include both the depth and the associated scientific knowledge (Treagust & Harrison, 2000).

The three levels of assessment developed for the study were *Sound Explanation (SE), Partial Explanation (PE)* and *Wrong Explanation (WE)*. Explanations that were given out of deep reasoning and articulated through adoption of scientifically accurate explanatory facts and theories that are related to the concept under investigation were categorised as Sound Explanations. Partial Explanations were those explanations that were given out of deep reasoning, but lacked the scientific accuracy associated with the concepts, or vice versa. Explanations that lacked both the deep reasoning behind it as well as considered scientifically inaccurate were categorised as Wrong Explanations.

2.4 Gender implications of the use of the POE model in teaching and learning science

Gender refers to the roles, behaviour, methods of expressing oneself, and identities that society has assigned to girls, women, men, boys, and others who do not fit into either gender (Connell, 2009). It tends to affect how people think about themselves and each other, how they act and talk to each other, and how power and resources are shared in society. People and groups have a different ways by which they understand, experience, and show their gender based on the roles they play, the expectations put on them, their relationships with others, and the complicated ways that gender is institutionalized in society (Sinnes & Løken, 2014; Abagre & Bukari, 2013; Evans, 2011). According to

Ogunkunle (2014), gender is dynamic and based on culture, which means that different responsibilities are given to boys and girls as they grow up. The author also indicates that gender is made up of the traits, behaviour, and roles that societies have given to men and women.

Society tends to hold the view that men are inherently better at some jobs than women are, while women are better suited to others (Evans, 2011; Connell, 2009). This is reflected by the widespread belief that men excel in technical and scientific fields, while women are better suited to other disciplines like nursing and child care (McEwen, 2013). These socially sanctioned norms of masculine and feminine roles and expectations of men and women tend to be reinforced through the disciplines. As Fink (2016) opines, gender is a social construction that defines male and female in terms of distinct social roles, psychological traits, and physical reactions. Similarly, West and Zimmerman (2017) as well as Wood and Eagly (2019), describe gender as the social characteristics and possibilities that come with being male and female, as well as the connections between men and women, and boys and girls. These characteristics, opportunities, and interactions are socially produced and acquired through the process of socialisation. Unfortunately, these stringent societal gendered presuppositions that tend to divide males and females seem to have led to unwarranted discrimination and marginalisation of girls and women that is not only detrimental to them, but undermines the developmental prospects of societies. As Baily and Holmarsdottir (2015) opine, gendered expectations can restrict individuals in physical, mental, and cultural ways and hinder them from receiving equitable treatment. Particularly for girls, gendered traditions such as coming-of-age rites and social pressure to marry and have children at a young age frequently result in persistent gendered marginalisation and hazards to their safety, advancement, and pursuit of formal education (Baily & Holmarsdottir, 2015).

It appears that in the African culture, particularly in Ghana, women are expected to be gentle, submissive, dependent, passive, emotional, and be seen but not heard. However, men are expected to be aggressive, independent, logical, strong-willed, and in charge. Thus, gender is seen as status, roles, and actions that are set by society and make men and women different (Awinpoka-Akurugu, 2021). In a Ghanaian household, it is common practice for parents to ask their sons to perform chores such as washing automobiles, cutting grass, fixing light bulbs, or climbing ladders to remove or replace items. On the other hand, the girls would be responsible for doing housework tasks like cooking, washing dishes, and cleaning, among other things (Boateng & Gaulee, 2019; Nguyen & Wodon, 2013). The authors further added that subjects that are regarded as complex and difficult such as Science are allocated to boys, whereas girls are expected to study relatively easier subjects. The National Gender Policy [NGP], 2015) of Ghana has its vision of *A stable, united, inclusive and prosperous country with opportunities for all*. Although the NGP provides broad policy guidelines, strategies and institutional framework to operationalise government's commitments for achieving gender equality and women's empowerment in Ghana, gender disparities appear to prevail in rural areas, homes, schools and workplaces (Andam et al., 2013; Boateng & Gaulee, 2019).

In science education, there has been a long-standing pattern of underrepresentation of females in the field of science, which appears to have been fuelled by the false belief that the study of science is the exclusive domain of males. There are also concerns that females are not achieving much in science compared to males, especially in the physical sciences

(Zander et al., 2015; Lee & Burkam, 1996). It appears common in many classrooms that fewer girls take advanced mathematics and science courses, choose science careers, and also, that boys tend to perform better in school than girls, especially when it came to the sciences. According to research, many females are of the view that physical sciences are associated to masculinity whereas the biological sciences are viewed as more feminine (Smyth & Nosek, 2015; Francis et al., 2017; Turnbull et al., 2017).

Many reasons have been attributed to these disparities in science education among females and males. According to Tracy (2016), gender disparities can be attributed to social factors such as sex role models and orientation, educational factors such as learning environments and teacher attitudes, and personal factors such as physiological and self-efficacy beliefs. The findings of several researches on students of different genders and what those findings mean for science have been highly equivocal and have led to a variety of different conclusions. Some researchers suggest a gender gap where boys are more successful than girls (Kingdon, 2015), while other researchers have found no significant difference between the sexes (Else-Quest et al., 2010; Ajayi & Ogbeba, 2017; Hyde et al., 2019), and still others have demonstrated that girls are more successful than boys (Calsambis, 2007; Soyibo, 2009; Kingdon et al., 2017).

Though the Predict-Observe-Explain (POE) model-based interactive instruction was not directly emphasised in the above studies, some references were made to the use of instructional strategies in the classroom. Moreover, the POE model-based interactive teaching strategy could be an effective strategy that could be adopted to close the gender gap among learners in their study of science. In this current study, there were mixed gender groupings in which both females and males were allowed to go through the stages of the

POE model-based interactions together. Both genders were assigned group leadership roles equally, and were made to lead discussions during the explanation stages of the model. Thus, this study explored the possibilities of the POE model-based interactive teaching approach to bridging the gender gap in science if any.

2.5 Empirical Studies on POE Model Strategy

This section reviewed some research works that had been carried out using the Predict-Observe-Explain model of teaching and learning in different countries, and at different levels of learners. Again, there was a review of literature on other teaching strategies apart from the POE strategy as used at the various levels of study. The findings of these reviewed works and their implications to this present study are thoroughly discussed.

A study by Erdem, Özcan and Uyanık (2022) employed a quasi-experimental design with pretest-posttest control group to investigate the effect of the Predict-Observe-Explain (POE) strategy on 4th grade students' academic achievement, attitudes towards science and retention. The study had 60 participants evenly divided randomly into the experimental and control groups. The activities in the intervention group were conducted for eight weeks and a total of 18 lesson hours were run. The pre- and Post-test results of the students in the experimental group and the control group were compared using the t-test for independent groups. The results of the study demonstrated statistically significant differences between the experimental and control groups in terms of both academic achievement and attitudes. In addition, the study applied a retention test five weeks after the Post-test application, and the test results revealed statistically significant difference between both groups in favour of the experimental group. Hence the authors concluded that POE is an effective strategy in increasing the academic achievement and providing positive attitudes towards science.

The present study was conducted in nine weeks with pre and Post-tests carried out in science lessons just as the reviewed study. While the reviewed study employed quasi-experimental design, the present study adopted the use of action research design. While the reviewed study sought to determine the effect of the POE strategy on 4^{th} grade students' academic achievement and attitude towards science and retention, this study worked with first year university science students. Thus, this study determined the effect of the POE strategy on the nature and quality of pre-service science teachers' explanations to concepts in science. While the reviewed study did not consider any gender implications, this study looked at gender differences in perceptions towards the use of the strategy among the pre-service teachers.

In Oluwasegun and Owolabi's (2021) study, the authors investigated the effects of Predict-Observe-Explain (POE) instructional strategy on students' performance and attitude towards Physics practical work in secondary schools in Nigeria. The study adopted the quasi-experimental design of Pre-test, Post-test and control group, using a sample of 54 Senior Secondary two (SS II) Physics students who were randomly selected through multistage technique from two co-educational Senior Secondary Schools in Osun State, Nigeria. The experimental group was exposed to predict-observe-explain instructional strategy while the control group was taught using conventional laboratory strategy. Physics Practical Test (PPT) and Physics Practical Attitude Scale (PPAS) were the two instruments used to collect relevant data for the study. Descriptive statistics and t-test were used to answer the research questions at significance level of 0.05. The findings from the study showed that the treatment had positive effects on students' performance and their attitude towards Physics practical work.

The reviewed study is similar to the current study in terms of the teaching strategy and the use of the Pre-tests and Post-tests. Though the participants, their levels, the data collection instruments, the research designs and the country settings differ in both studies, this present study had the objective of investigating the effect of the POE strategy on science students' science learning. Hence, this study sought to find the effect of the POE model-based teaching strategy on the nature and quality of pre-service science teachers' explanations to concepts in science.

A study by Nalkiran and Karamustafaoglu (2020) was designed not only for teaching science concepts such as "work, energy and power" and the relationships among them, but also to investigate the effects of teaching on students' achievements under the POE method. The study sampled six students from the 9th grade studying at a private Anatolian High School chosen through easily accessible case sampling method; and employed four data collection tools (semi-structured interview, open-ended achievement test, concept map and concept cartoon). The authors carried out the study within the scope of a single group pretest-posttest simple experimental design, and used the quantitative research method. They analysed the data with gap and content analysis methods, and through interviews, open-ended achievement test and concept map, as Pre-tests, determined that the students had many misconceptions about "work, energy, power" concepts. They also found out that many of the students did not have any scientific knowledge about the relationships among the science concepts, and the students portrayed relationships that were far from scientific. After the concept teaching under POE was performed, the authors reapplied the data collection tools as Post-tests. The results were that the students' misconceptions were largely eliminated and had been replaced with scientifically-correct concepts and relationships as a result of that process. They thus concluded that applying POE method in concept teaching on different classes, courses or subjects is highly recommended.

The implications of this reviewed study on this present study are that both studies sought to determine the outcome of the use of the POE teaching strategy on students' learning of science. While the reviewed study sampled only six (6) ninth grade students, this study sampled 250 first year university students. Though the present study did not use interviews and concept maps as data collection instruments the reviewed study did. However, both studies employed open-ended Pre-tests and Post-tests questions and used the content description approach to analyse collected data. The findings of the reviewed study revealed the positive impact of the POE strategy in eliminating students' misconceptions in the selected science concepts. Hence, this study employed similar teaching strategy (POE) to assess the effect on the pre-service teachers' explanations to concepts in science, which could emanate from their conceptual understanding of the concepts.

Venida and Sigua (2020) employed a quasi-experimental approach using the pretest-posttest design to determine the effect of the Predict-Observe-Explain (POE) Strategy on students' achievement and attitude towards physics. The study sampled 59 grade seven students from two intact classes, in which the control; group were taken through the 5E's (engage-explore-explain-elaborate-evaluate) learning cycle, while the POE strategy was utilised in teaching the experimental group. The findings indicated that the Inquiry-based strategy using the 5E's learning cycle and Predict-Observe-Explain strategy were both potential strategies in enhancing the students' academic achievement in science. However, the students who were taught using the POE strategy performed better and registered a more positive attitude towards the subject after the intervention than the students who were taught using the 5E's learning cycle. Thus, the authors suggested that the POE strategy positively influenced the academic performance and attitude of the students towards physics.

The reviewed study has implications for the present study, in that, the former sought to determine the effect of the POE teaching and learning strategy on students' learning of physics, just as the latter seeks to do. Although the reviewed study employed the quasi-experimental approach which the present study did not, both control and experimental groups of the study were intact classes. This present study also engaged an intact class of all Level 100 students of a university. However, the present study did not engage students through the 5E's learning cycle. The findings of the reviewed study proved that the learners performed better and registered a more positive attitude towards the study of science; and that, POE strategy positively influences the academic performance and attitude of the students towards science. Therefore, this study determined the effect of the POE model-based strategy on the nature and quality of scientific explanations of pre-service teachers to concepts in science, as well as their perceptions of the model.

A study conducted in Indonesia by Jasdilla, Fitria and Sopandi (2019) was to test the effect of the Predict-Observe-Explain (POE) strategy on change in the mental model of fifth grade learners in material of light. The research used the quantitative approach adopting the quasi experimental design. The study purposively used a sample of class V students in one of the elementary schools in a village of Lembang sub-district; collected data with objective tests as well as a two-tier test and analysed the date with descriptive and inferential statistical tools. The findings of the research revealed that the POE strategy had an effect on the change of mental model of the primary students. The findings further revealed that students' mental models developed and were well-formed due to the experiences they gained in learning, which were not based on rote memorisation. However, through the POE strategy, they were trained to create hypotheses (conjectures) on a phenomenon.

This reviewed study has implications for this present study although the category of students involved was in primary school and also the country was Indonesia. Again, though the reviewed study also employed quantitative approach just as this study, it adopted the quasi-experimental design. However, the reviewed study has some similarities with this present study in that, the POE teaching strategy was used for both studies. The present study also adopted the quantitative approach though an action research design was employed. This study also made use of two-tier tests and analysed data in a similar way as the reviewed study. The reviewed study made findings indicating that the POE strategy had an effect on the learners' change of mental modes. Therefore, this present study seeks to determine if the POE model-based teaching strategy could have an effect on the nature and quality of pre-service science teachers' explanations to concepts in science.

Another study by Demircioğlu, Demircioğlu, and Aslan (2017) also examined how the Predict-Observe-Explain (POE) approach impacted grade 11 Chemistry students' comprehension of Trabzon's gases. The study was quasi-experimental and randomly picked two Trabzon Anatolian high school classes, designated as experimental group (N=36) and control group (N=37). The authors used the Gases Concept Test (GCT) with 20 multiple-choice questions, and KR-20 was 0.84. Eight (8) POE-based exercises were created for the experimental group while the control group was taught traditionally. The study's research question was answered by calculating the mean and standard deviation of the relevant scores, and the null hypothesis was tested using an analysis of covariance. The outcome showed that the Predict-Observe-Explain-taught experimental group outperformed the control group in all measures.

The implications of the reviewed work to the present study are that, in terms of teaching strategy, both adopted the use of the POE model. However, the reviewed study from Turkey, used the quasi-experimental approach, sampled grade 11 chemistry students and conducted multiple choice Gas Concept Tests; while the present study from Ghana, was an action research using an intact group of Level 100 students, and conducted open-ended pre and Post-tests. The results of the reviewed study showed that the experimental group taught with the POE strategy performed better than the control group taught in the traditional manner. Hence, this study determined if the use of the POE model in teaching the pre-service science teachers had a positive impact on their performance in terms of providing scientific explanations of the right nature and quality to concepts.

Karamustafaolu and Mamlok-Naaman (2015) studied the Predict-Observe-Explain technique for comprehending electrochemistry topics in their study which focused on first-year students in the Department of Science, Faculty of Education of Amasya University, Turkey. The purpose of the study was to examine the impact of teaching electrochemistry principles with the Predict-Observe-Explain (POE) technique. The study employed a quasi-experimental design with 20 participants in the experimental group (EG) and control group (CG), and was directed by two research questions and two null hypotheses. The pre- and Post-tests consisted of an Open-Ended Test (OET) and a Multiple Choice Test (MCT), respectively. Mean (M) and Standard Deviation (SD) scores were utilised to answer the study questions, whilst Analysis of Covariance (ANCOVA) was utilised to evaluate the hypotheses. The findings of the study indicated that the Predict-Observe-Explain technique improved students' understanding of electrochemistry topics substantially more than the lecture method.

The reviewed study focused on first year students of a university in Turkey, and how the POE strategy impacted their understanding of concepts in science. These are similar to this present study which also focused on first year pre-service science teachers of a university in the science department, though the present study was conducted in Ghana. Although the reviewed study used the quasi-experimental approach, the current study used an intact group of students and adopted the action research design. The pre and post tests conducted were aligned to that used by the present study and this study also used open ended tests. The findings of Karamustafaolu and Mamlok-Naaman (2015) indicated that the POE strategy made an impact on the students' understanding of concepts in science. Hence, this present study determines the effect of the POE strategy on the nature and quality of first year students' explanations to concepts in science, which could stem from their understanding of concepts.

Zacharias (2005) conducted a study in Cyprus, and investigated how individuals' construction of explanations develops from interactive simulations. The author determined the effect of interactive computer simulations or science textbook assignments on the nature and quality of postgraduate science teachers' explanations regarding concepts in Mechanics, Waves/Optics, and Thermal Physics. The use of simulations or science textbook assignments was implemented according to the Predict–Observe–Explain (POE) model and integrated into a one-semester conceptual survey course for a sample of practicing science teachers. Data were collected through semi-structured interviews and analysed using a qualitative content analysis approach. Results of the study indicated that the use of computer simulations along with the application of the POE model had a positive impact on the nature and quality of science teachers' explanations. Further, it was revealed that the science teachers had improved in their ability to generate scientifically accurate explanations and fostered in-depth advancement in their provision of explanations to concepts under investigation. The study added that the teachers' explanations became more elaborate, reflecting cause-effect reasoning and formal reasoning.

This study, using pre-service science teachers as its sample, incorporating interactive teaching strategies and adopting the POE model was conducted to determine the effect of these teaching strategies on students' explanations in science. The present study was however conducted in a Ghanaian university and used tests and questionnaire instead of semi structured interviews used in the reviewed paper. With the results attained in the reviewed paper, this present study determined if the POE model-based interactive teaching strategy had an effect on the nature and quality of explanations of the teachers to concepts in science.

Zacharia and Anderson (2003) conducted a study that investigated the use of the Predict-Observe-Explain model in science education. The study aimed to determine the effect of using the model on the quality of scientific explanations given by pre-service physics teachers. The study found that pre-service teachers who used the POE model showed improvement in their understanding of scientific concepts and were able to provide more accurate and detailed explanations compared to pre-service teachers who did not use the POE model. The results of this study suggest that the POE model can be a useful teaching approach for pre-service teachers, as it can help them to better understand scientific concepts and improve their scientific explanations.

This study is also conducted on the use of the POE model-based strategy, and its effect on pre-service teachers' explanations to concepts in science. Although the reviewed study was conducted in Turkey, this study conducted in Ghana had similar objectives of determining how the POE model impacted pre-service teachers in providing quality explanations to concepts. The reviewed study revealed that pre-service teachers who used the POE model showed improvement in their understanding of scientific concepts, and could provide more accurate and detailed explanations compared to pre-service teachers who did not use the POE model. Thus, this present study sought to determine the impact of the POE model-based teaching strategy on the quality of explanations of pre-service science teachers.

Many studies on the use of the POE teaching strategy in various contexts and with various participants have yielded results indicating that the POE process can facilitate students' self-corrections and self-adjustments, improve their learning performance, and help them gradually eliminate scientific misconceptions (Lu et al., 2008; Chen et al., 2013; Pedaste et al., 2015). Other studies by other researchers have also demonstrated the effectiveness of the POE technique in scientific teaching (Karaer, 2007; Hong et al., 2021). As a result, it is considered that the POE technique is useful for helping students learn concepts, build positive attitudes, and boost their interests in scientific courses (Bilen & Aydoğdu, 2010; Tokur, 2011).

2.6 Philosophical Underpinnings of the Study

The constructivist paradigm, which has its roots in the interpretivist paradigm of philosophy, is well-suited to this study. According to Honebein (1996), the constructivism philosophical paradigm is an approach that asserts that people construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences. The constructivist philosophy is based on the idea that teachers do not have to stand in front of the class and lecture for students to learn. However, constructivists believe that learners only learn when they uncover truths for themselves through explorations and manipulations (Kalender, 2007). The best option, according to constructivist philosophers, is for the student to be fully involved in the teaching and learning processes. This way, the student can discover the knowledge or "truth" for him or herself (Adom et al., 2016).

The main distinction between constructivism philosophy and positivism relates to the fact that while positivism argues that knowledge is generated in a scientific method, constructivism maintains that knowledge is constructed by scientists and it opposes the idea that there is a single methodology to generate knowledge (Hasa, 2020).

According to Dudovskiy (2018), the most popular types of constructivism paradigm are illustrated in Table 1 below.

Table 1: Types of constructivism and their explanations

Type of Constructivism	Explanation
Epistemological Constructivism	Knowledge is created by human perception and social experience
Social Constructivism	Knowledge and reality are created by social relationships and interactions
Psychological Constructivism	People create systems to understand their world and experiences

This study relates to the social constructivism paradigm, which emphasises the importance of interactions in acquiring knowledge. Thus, through this study there were opportunities for various interactions, and through that, learners were led to discover the meanings of science concepts.

The Predict-Observe-Explain (POE) as a constructivist strategy acknowledges the fact that students are not blank slates when they enter the classroom. Rather, they have a variety of experiences, which is why much emphasis was placed on the significance of students' prior knowledge in the acquisition of knowledge (Bajar-Sales et al., 2015; Demirbaş & Pektaş, 2015). The POE strategy was instrumental in leading learners to self-exploration, self-discovery and self-learning through the use of science process skills such as predicting, observing and explaining. These enhanced their abilities to make predictions using their pre-existing ideas as the basis for constructing scientific explanations to concepts (Akinbobola & Afolabi, 2010; Hilario, 2015). Due to the constructivist nature of the learning environment, throughout the research, the researcher did not impose herself as the leading figure dictating and transmitting information; but rather acted as a facilitator and guide for the learners in constructing their own learning.

The methodology of the research was in line with the constructivist approach, and as such, open-ended questions were used. Students were made to express their answers after thorough discussions among themselves and after finally arriving at a common answer by all. Thus, the paradigm served as a guiding principle for this study.

2.7 Summary of the Chapter

The study looked at the idea of using the Predict-Observe-Explain model-based teaching and learning strategy to ascertain its effect on the nature and quality of pre-service science teachers' explanations to concepts in science. The theoretical frameworks on which this study was hinged were carefully examined vis-à-vis the POE teaching strategy. The conceptual framework of the study indicating how the interrelatedness of the dependent, independent and extraneous variables were outlined. Relevant literature relating to the study was reviewed. These included literature on some methodologies of teaching and learning as well as the POE model-based teaching and learning strategy. Two different types of scientific explanations - the Deductive-Nomological model and the Reason-Seeking model and how they differ in their structures and requirements were also reviewed. There was a thorough review of Kaartinen and Kumpulainen's (2002) scale for categorising the nature of scientific explanations which was adopted for this study; and categorised nature of an explanations into Formal, Causal, Descriptive, and Everyday. Furthermore, the study outlined the criteria for determining the quality of scientific explanations using a scoring criterion which categorised quality of an explanation as Sound, Partial, or Wrong, based on both the depth of reasoning and the scientific accuracy of the explanation. The chapter ended with a discussion on gender perspectives to the POE model-based teaching and learning, some empirical studies on the concepts under discussion, and the research paradigm or philosophical underpinnings of this study.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter begins with an outline of the research questions and hypotheses which guided this study. It presents the research design, indicating the research approach and also describes the area where the study was conducted. The participants and how they were sampled, the research instruments and the data collection procedures are also outlined. The chapter further outlines the validity and reliability methods that were used to check the research instruments, as well as the data analysis procedure. Concluding the chapter is the ethical considerations that were made.

3.1 Research Questions

The following questions guided this research:

1. What is the nature of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
2. What is the nature of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
3. What is the quality of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
4. What is the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
5. How do pre-service teachers perceive the use of the POE model-based interactive teaching of concepts in science?

6. What is the difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science?

3.2 Research Hypothesis

Research question 6 was further developed into research hypothesis as follows:

- Null hypothesis (H_0: $\mu=0$): There is no statistically significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

- Alternative hypothesis (H_1: $\mu \neq 0$): There is a statistically significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

3.3 Research Design

The research design used in this study was a Pre-test/Post-test quasi-experimental design. This is because the study involved a pre-intervention phase (Pre-test), intervention phase (observation), and post-intervention phase (Post-test), and the participants were not randomly assigned to groups since the study did not include a control group (Jhangiani et al., 2019). Data was collected on the quality and nature of the students' explanations to science concepts before and after the intervention, which allowed for a comparison of their conceptual understanding and explanations of scientific concepts.

The study adopted an action research approach involving both quantitative and qualitative strategies. This is because integrating both approaches in action research allows for a more comprehensive understanding of the research problem and a more robust analysis of the data (Ivankova & Wingo, 2018). The combination of quantitative and qualitative data collection and analysis methods enabled triangulation of findings from different sources, which increased the credibility and validity of the research (Creswell & Plano Clark, 2018). Quantitatively, the study used the pretest-posttest design to collect data on pre-service science students' explanations to science concepts; and qualitatively, data was collected on their perceptions of the POE model-based teaching strategy which served as the intervention for the study.

Specifically, in this study, participants were taken through a course coded INS 123 and titled Heat and Thermodynamics, using various interactive teaching and learning resources from both soft and hard copies of the Conceptual Physics Package (Hewitt, 2015). The study used the POE (Predict-Observe-Explain) model as a teaching strategy, and collected both quantitative data (pre-tests and post-tests data) and qualitative data on views about the intervention strategy which was used to evaluate the effectiveness of the teaching strategy on the students' explanations to the science concepts.

3.4 Area of Study

The study area is Winneba, Ghana. Winneba is a town and the capital of the Effutu Municipal District in the Central Region of Ghana. It lies along the Gulf of Guinea near the mouth of the Ayensu River, and has a population of 55,331. Traditionally known as *Simpa*, the town is a historic fishing port in Ghana, lying on the south coast, 140 kilometres (90 miles) east of Cape Coast. It is also approximately 56 kilometres (35 miles) west of Accra, the capital city of Ghana (Winneba Open Digital Village[WODIV], 2009).

Winneba is a vibrant town in Ghana, with the University of Education, Winneba (UEW) as one of the prominent institutions, providing valuable experiences for students at various stages of their academic journeys. UEW is renowned for producing highly skilled and competitive professionals in the field of education and beyond. Recognised as one of the top universities in the country, UEW places a strong emphasis on research-based teaching, ensuring the delivery of excellent education. With a faculty composed entirely of professional educators, students benefit from the expertise and guidance of experienced industry professionals who bring real-world insights into the classroom. The University promotes diversity, equity, and inclusion and has made efforts in identifying and eradicating inequality in both practises and systems. Hence, the University continues to enrol, train, and assist students with diverse abilities, and places value on diversity, gender equity and social inclusion (University of Education, Winneba[UEW], 2019). The Integrated Science Education programme is one of the many programmes that UEW offers. Its goal is to train pre-service students to become competent and successful science teachers at the pre-tertiary levels in Ghana. The programme trains students who want to become professional teachers so they can obtain both the knowledge and abilities they need to teach science effectively in the classroom. The choice of this study area was premised on the fact that there was scarcity of information on the use of the POE model-based teaching and learning strategy and its effect on students in the Integrated Science Education programme at the University of Education, Winneba.

3.5 Population, Sample and Sampling Technique

The population for the study was all Integrated Science students of the Department of Integrated Science Education of the University of Education, Winneba. However, due to the large numbers of students at the various levels, only Level 100 students of a total enrollment of 251 were purposively sampled for the study. They were purposely selected because the Level 100 students were students attending university for the first time. This group of students had gone through the pre-tertiary level of education and are exposed to other methods of science teaching and learning. They were therefore in a good position to impact the POE model-based teaching and learning on them better than students in other levels. The sample was also among the group of students taught by the Researcher and was therefore easily accessible for the purposes of the study.

3.6 Data Collection Instruments

The study collected both quantitative and qualitative data using pre-and-Post-test items and a questionnaire. Quantitative data was collected through scores obtained from the pre-tests and post-tests, which were used to evaluate the effectiveness of the POE model-based teaching strategy on the participants. The open-ended question items used in both the Pre-tests and Post-tests enabled a qualitative analysis of the students' responses. Qualitative data was collected through views and feedback from the pre-service teachers about the intervention strategy and their perceptions of the model. This was done using a questionnaire.

3.6.1 Pre and Post Tests

Quantitative data was gathered with the use of Pre-tests and Post-tests. The Pre-tests were used to diagnose the nature and quality of the students' explanations to seven science concepts (Heat & Temperature, Thermal Expansion, Quantity of Heat, Specific Heat Capacity, Thermal Conduction, Thermal Convection and Thermal Radiation), used for the study. These concepts are part of the content of Heat and Thermodynamics as a course of study at Level 100. The Pre-tests were conducted during the first 30 minutes of the lesson. There were five (5) different Pre-tests for the study, with each made up of three (3) open-ended questions based on pre-reading assignments on a given concept.

The Post-tests were designed in the form of two-tier worksheets, developed from the same concepts used for the study. The worksheets were developed by the Researcher in consultation with the supervisors of this study. The Post-tests were used to assess the students' answers to the Post-test questions. The Post-tests assessed the participants' progress from informal to formal explanations, and to determine their levels of advancement based on accepted explanations.

Each of the five (5) two-tier Post-test worksheets comprised three (3) two-tier multiple-choice questions, followed by an open-ended question. The first tier of each item consisted of a multiple-choice question with answer options from which participants were expected to choose their own correct answer. There is only one correct answer within the options and the rest distractors, while the second tier elicited justifications or reasons for the chosen option made in the first part. According to Shin, Guo, and Gierl (2019), distractors are intended to distinguish between students who have not yet acquired the scientific knowledge necessary to answer the item correctly from those who understand the content. Therefore, distractors in a multiple-choice item are designed to contain plausible but incorrect answers based on students' common errors or misconceptions so that the option can measure students' level of mastery in a specific content area.

The nature and quality of the students' explanations given in the second tiers were assessed using the same criteria developed for assessing the Pre-tests. The items developed for both Pre-test and Post-test questions were selected from the recommended textbook used for the course of the study, and hence the difficulty level was within the comprehension of the pre-service science students.

3.6.2 Scoring Criteria for Pre and Post-tests Items

This study intended to determine the nature and quality of science explanations given by the participants. The nature of an explanation was assessed based on the participants' ability to construct explanations of scientific concepts using formal language of science. This assessment was performed on each of the five Pre-tests and five Post-tests conducted in the study. In scoring the nature of an explanation, the study adopted the criteria developed by Kaartinen and Kumpulainen (2002) in their study to categorise scientific explanations based on the use of formal language of science. In this study, the students' explanations to the open-ended questions were numerically coded to categorise them based on the use of formal language of science. The category of formal explanation (FE) was assigned a score of 3, and defined as explanation which utterly reflected those given by experts of the scientific domain. A causal explanation (CE) included any explanation that gave the cause and effect of phenomena with the help of informal language. Causal explanations were assigned a score of 2. Explanations which were characterised by only the process of a phenomenon without identifying specifically any causal relationships were categorised as descriptive explanations (DE), and assigned a score of 1. Everyday explanations (EE) only reflected the creation of situational meanings derived from informal contexts, and were assigned 0. Their criteria are detailed in Table 2.

Table 2: Scoring Criteria for Nature of an Explanation

Nature of Explanation	Description	Score
Formal Explanation (FE)	Explanation which totally agreed with those given by experts of the scientific domain.	3
Causal Explanation (CE)	Explanation which gave only the cause and/or result of a physical phenomenon, informal in nature and not necessarily congruent with those of experts.	2
Descriptive Explanation (DE)	Explanations that provided the process of a physical phenomenon but did not identify specifically any causal relationships.	1
Everyday Explanation (EE)	Explanations that reflected the creation of situational meanings derived from informal contexts.	0

In this study, explanations that were considered acceptable included Formal Explanations (FE) and Causal Explanations (CE). These categories reflected a higher level of conceptual understanding and proficiency in the use of formal language of science, with Formal Explanations being the most desirable. However, explanations in the categories of Descriptive Explanations (DE) and Everyday Explanations (EE) were rated low and unacceptable. These explanations reflected informal understanding of concepts, and the use of situational, context-specific meanings without the use of formal language of science.

Scoring of the quality of an explanation was based on a marking criterion which was adopted from the study by Costu, Ayas, Niaz, Unal and Calik (2007) in which they analysed the quality of explanations given by students for the open-ended Pre-test items. The students' explanations to the open-ended questions were content coded to categorise them for scientific accuracy. A numerical scale was used for rating the scientific accuracy and degree of deepening of an explanation. On this scale, a score of 2 was for most accurate, where there was the accurate use of scientific concepts and theories and coherency in understanding was evident. Score of 1 was for partially accurate, where students exhibited partial knowledge of the phenomena. However, if ideas were not presented in an integrated or unified way, then it is an indication of some level of understanding. A score of 0 was for least accurate, showing confused and contradictory explanation, which is an indication of minimal understanding. The scoring criteria also included information about an explanation's legitimacy/appropriateness (use of scientifically accepted concepts and theories) according to D-N or reason-seeking explanation model. Hence, the assessment of the quality of an explanation involved checking the rationality of statements that made reference to underlying scientific reasons/principles.

The scoring criteria for quality of explanation are summarised in Table 3.

Table 3: Scoring Criteria for Quality of an Explanation

Quality of Explanation	Description	Score
Sound Explanation (SE)	Explanations involving accurate use of scientific concepts and theories, where coherent understanding is evident (the explanandum should be a logical consequence of the explanans). Scientifically accurate explanations.	2
Partial Explanation (PE)	Explanations that indicated partial knowledge of the phenomena, where ideas are not presented in an integrated or unified way, showing some understanding is evident. Partially accurate explanations.	1
Wrong Explanation (WE)	Confused and contradictory explanation exhibiting minimal understanding. Inaccurate explanations.	0

In this study, explanations that scored higher (2) in terms of scientific accuracy and coherence were considered to be of higher quality and sound. The explanations that scored lower (1 or 0) indicated partial or minimal understanding, respectively and were rated as low quality.

3.6.3 Questionnaire on Perceptions of POE Model-based Teaching and Learning

The Questionnaire on Perceptions of POE (QPPOE) Model-based Teaching and Learning strategy is a mixed-methods instrument designed to elicit both quantitative and qualitative data on the participants' perceptions of the POE model-based teaching and learning strategy in their study of science. The questionnaire consisted of nineteen items, thirteen of which were closed-ended and required participants to respond to a five-point Likert type scale coded Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4) and Strongly Agree (5), while six were open-ended, which sought participants' free expressions, opinions, and suggestions about the POE teaching and learning model. The close-ended items were indicators categorised into constructs, while the open-ended items were put into themes. The use of both closed-ended and open-ended items in the QPPOE allowed more insight into the participants' perceptions of the POE model-based teaching and learning.

To aid in the analysis of the gathered data, the questions on the QPPOE were classified into three themes. These themes were determined based on how the students perceived their conceptual learning in science (Cognitive perceptions), their attitudes towards studying science (Behavioural perceptions), and their interests and motivations in science learning (Emotional perceptions). Consequently, each closed-ended item was assigned to one of these three themes to facilitate the analysis.

3.7 Validity of the Instruments

Validity measures how well a test or tool fits the function for which it is used (Downing, 2006). Thus, in terms of assessment and testing, it could be described as a measure of the extent to which a test measures what it is supposed to measure. The instruments were checked by the researcher's supervisors, other senior researchers of the Faculty of Science Education of UEW, and colleagues to ascertain the face and content validity of the instruments.

According to Shoukat, Chaudhry and Ikram (2019), face validity is the extent to which a research instrument appears to measure what it is intended to measure. To ensure good face validity of the instruments, a team comprising the Researcher, supervisors and two other Science Education researchers evaluated the items in the instruments to ensure good face validity.

One aspect considered during the evaluation was to check for *Clarity of instructions and items.* The aim was to ensure that the instructions and items were clear and easy to understand, using language that was appropriate for the students and avoiding excessive technicality or confusion. Another aspect the team checked was *Relevance of the items*, which was to ensure that the items in the instruments were relevant to the construct being measured, appearing important and meaningful to the respondents. Additionally, the *Appropriateness of the items* was checked. This was to ascertain if the items in the instrument were appropriate for the students, and that the context in which they were administered was not offensive or inappropriate in any way. Finally, the items were checked to ensure the *Absence of obvious errors*. Hence, the instrument was thoroughly reviewed to eliminate any spelling or grammatical errors, as well as inconsistencies in the wording of items.

To ensure content validity of the questionnaire, that is, the degree to which the items on the instrument represented the domains of interest, the content validity index (CVI) of the items was determined. Polit and Beck (2006), define CVI as a numerical score that indicates the degree of agreement among experts about the relevance and representativeness of each item in a research instrument. A CVI score of at least 0.80 is considered acceptable for the instrument to be deemed relevant or representative enough. In this study, the content validity index was checked through the steps outlined below.

A panel of three (3) Science Education researchers knowledgeable in the field of research was constituted. The panel rated each item for its relevance and representativeness, using a 4-point Likert type scale (Appendix L) to rate each item. This scale was coded Not Relevant or Represented (1), Somewhat Relevant or Represented (2), Relevant or Represented (3) and Highly Relevant or Represented (4).

The CVI was then calculated by first, determining the proportion of items that were rated as highly relevant and/or relevant or representative by the experts, this was divided by the total number of items, and the results for each expert noted. Finally, adding up the CVI scores for all the experts and dividing by the total number of experts gave the CVI for the entire questionnaire (Polit & Beck, 2006). The CVI score for this study was 0.86.

3.8 Reliability of the Instruments

Reliability refers to how consistent the results from the test are, or how well the test is actually measuring what you want it to measure (Price et al., 2015). Cronbach's alpha analysis was used to determine the reliability of the items of the questionnaire (QPPOE). According to Emerson (2019), Cronbach's alpha is calculated to show the level of internal consistency within a group of items, and a high Cronbach's alpha indicates that the items being assessed are highly correlated with each other. It can range from 0 to 1, and an acceptably high value is usually taken as 0.7 or 0.8 and above.

In this study, the Cronbach's alpha analysis of the questionnaire items gave reliability value of 0.80 (Appendix N), which was an acceptable indication of the internal consistency of the items of the QPPOE. According to Sijtsma (2009), a Cronbach's alpha of 0.70 is generally considered an acceptable level of internal consistency.

3.9 Data Collection Procedures

This section outlines the procedures that were carried out to collect data for the study. The duration and structure, as well as the various stages of the study are outlined in this section.

Duration and Structure of the Study

The study was conducted over a period of nine (9) weeks in the second semester of the 2021/2022 academic year, where seven science concepts from the course Heat and Thermodynamics were taught. The concepts taught and used for the study were Heat and Temperature, Thermal Expansion, Quantity of Heat, Specific Heat Capacity, Thermal Conduction, Thermal Convection and Thermal Radiation. The pre-service students were given access to the course manual of the course where all the concepts to be learnt had been outlined. The reading assignments and the specific areas which needed to be studied or read before each lesson were indicated in the manual as well. These were thoroughly discussed with the students during the first week of the study. A sample lesson plan (Appendix O), indicates how each lesson was conducted during all the three phases of the study using the POE model-based interactive teaching strategy.

Pre-Intervention Phase (Prediction)

This was the first step of the POE strategy, and took place as a Pre-test during the first 30 minutes of each lesson. This phase represented the Prediction stage of the study. Five (5) Pre-tests were conducted to diagnose the nature and quality of the students' explanations based on their prior knowledge gained from the reading assignments. That is, during these Pre-tests, the participants would commit themselves to a prediction for a particular outcome or phenomenon before being made to observe (interacting with/studying/engaging in) the actual activity of the lesson.

To determine the nature of the students' explanations, the Nature of Explanation Evaluation Form (NEEF), outlined in Table 4 was developed to collect data from the Pre-tests.

Table 4: Nature of Explanation Evaluation Form (NEEF) for Pre-tests

Group/Student	Assessment (nature of explanation)	Pre-test 1	Pre-test 2	Pre-test 3	Pre-test 4	Pre-test 5

The quality of the scientific explanations provided by the students for the Pre-tests was also assessed for depth of reasoning and scientific accuracy (quality). This data was collected with the aid of the Quality of Explanation Evaluation Form (QEEF), outlined in Table 5.

Table 5: Quality of Explanation Evaluation Form (QEEF) for Pre-tests

Group/Student	Assessment (quality of explanation)	Pre-test 1	Pre-test 2	Pre-test 3	Pre-test 4	Pre-test 5

Intervention Phase (Observation)

During the second (observation) phase of the study, pictures, illustrations, texts, simulations, videos and other interactive materials from the Conceptual Physics textbook (Hewitt, 2015) were then used to explain/teach the concepts. PowerPoint presentations, videos, simulations, group presentations, and other forms of interactions were employed by the researcher throughout the study. To cater for cooperative learning and active verbal discourses among the students, the participants were placed in small mixed (gender) groups of 3-4 in each group for the interactions. Thus, there were 73 groups in all, who actively engaged each other through discussions, debates and other forms of engagements to arrive at conclusions, and also to make detailed observations of the phenomena under study. After these interactions, which were facilitated by the researcher as a guide on the side, each group provided feedbacks on their earlier predictions, by explaining any discrepancies between their predictions and observations. These explanations were made by providing explanations to open-ended questions similar to the Pre-test items.

Post-Intervention Phase (Explanation)

The final phase of each lesson was the explanation phase which was carried out during the last 30 minutes of the lessons. During this phase, the students made reconciliations between their predictions and their observations by writing Post-tests. At this stage, the students had to make reconciliations between their earlier predictions and observations, and agree on the correct responses to the questions. The Post-tests allowed the researcher to check how the students had progressed from providing informal explanations to formal explanations, advanced in their depths of reasoning and achieved accuracy in their scientific knowledge.

The five (5) Post-tests conducted for the study were also evaluated for the nature and quality of the students' explanations to the concepts.

Table 6 was designed to collect data on the nature of students' explanations to questions from the Post-tests. The number of students in each category with its corresponding percentage was assessed and displayed using the Nature of Explanation Evaluation Form (NEEF) on Table 6. This categorisation was done for all the Post-tests.

Table 6: Nature of Explanation Evaluation Form (NEEF) for Post-tests

Group/Student	Assessment (nature of explanation)	Post-test 1	Post-test 2	Post-test 3	Post-test 4	Post-test 5

To collect data on the depth of reasoning and scientific accuracy (quality) of the students' explanations provided in the Post-tests, the Quality of Explanation Evaluation Form (QEEF) as shown in Table 7 was used. This Table was used to collect data from all the five (5) Post-tests of the study.

Table 7: Quality of Explanation Evaluation Form (QEEF) for Post-test

Group/Student	Assessment (quality of explanation)	Post-test 1	Post-test 2	Post-test 3	Post-test 4	Post-test 5

Students' responses to the open-ended items for both pre and post tests were coded into categories using the scoring criteria. This categorisation was carried out in three steps. Firstly, students' responses were classified by both the researcher and two other research assistants for each test separately. Secondly, in each of the scorings, all researchers coincided in about 80% or more of the classifications. Finally, all differences or disagreements were resolved by discussion. Students' responses to the open-ended items went through these processes to provide inter-rater validity of the scores.

The questionnaire on students' perceptions about the POE teaching strategy (QPPOE) was administered during the last week of the study. Students expressed their opinions on the teaching strategy by providing answers to both open-ended and closed-ended questions. The closed-ended questions had a five-point Likert type scale ranging from Strongly Agree (SA) coded 5 to Strongly Disagree (SD) coded 1, while the open-ended questions gave room for the students to provide their opinions on the teaching strategy.

To facilitate the analysis of the collected data, the items on the QPPOE were categorised into three themes. These themes were specified as a result of how the students perceived their conceptual learning of science (Cognitive perceptions), attitudes towards their study of science (Behavioural perceptions) and interests/motivations in their science learning (Emotional perceptions). Consequently, each of the closed-ended items was grouped under one of these three themes for analysis purposes.

3.10 Data Analysis Procedures

Data collected from each of the tests and the questionnaire were analysed using the Statistical Package for the Social Sciences (SPSS) software version 25.0, and were expressed in tables, charts and graphs using descriptive analysis. Inferences were then made from the descriptive data sets.

3.11 Ethical Considerations

Issues concerning ethics in research have become prominent in response to society's expectation of greater accountability (Fleming & Zegwaard, 2018). According to the authors, the cornerstones of ethics in research are 'informed' and 'consent'. Anonymity and confidentiality are important steps taken in protecting the participants from potential harm. Therefore, in this study, the issues of anonymity and confidentiality were upheld, participants were informed and their consent sought before data was collected. The purpose of the study, intended outcome, procedure and what entails participation, confidentiality and right of participation were made known to participants.

3.12 Summary of the Chapter

Chapter 3 elaborated on the research methodology that underpinned this study. The tenets of the action research design, on which this study hinged, as well as its implication for the study were also examined. The study purposively sampled all 251 Level 100 students of the Department of Integrated Science who studied the course Heat and Thermodynamics (INS 123) in the second semester of the 2021/2022 academic year. Using the Predict-Observe-Explain model-based teaching strategy, the participants were taken through seven concepts of the course where they wrote ten (10) pre and Post-tests, and answered a questionnaire, the QPPOE during the nine-week period of the study. Cronbach alpha reliability analysis of the questionnaire gave a score of 0.80, while face and content validity of the test items and questionnaires conducted also yielded high scores indicating that the items were valid. The procedures used for data collection from both instruments were thoroughly discussed after which an outline of how the data analysis was conducted using the SPSS version 25. Concluding the chapter was a description of the ethics considered during the study.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.0 Overview

The results obtained in the study are presented in this chapter. The presentations are outlined in the form of tables, charts and graphs arising from descriptive analysis. The descriptive analyses were conducted along the research questions and hypotheses of the study. The research questions and hypotheses are:

1. What is the nature of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
2. What is the nature of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
3. What is the quality of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?
4. What is the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?
5. How do pre-service teachers perceive the use of the POE model-based interactive teaching of concepts in science?
6. What is the difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science?

- Null hypothesis (H_0: $\mu=0$): There is no statistically significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

- Alternative hypothesis (H_1: $\mu \neq 0$): There is a statistically significant difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science.

4.1 Results of the Study

As already mentioned, the data collected using the instruments developed for the study were analysed, and the results presented and interpreted based on the research questions and hypotheses formulated. The study involved a total of 251 participants who were organised into mixed-gender groups consisting of 3 to 4 students in each group. As a result, a total of 73 groups were formed and participated in both the pre-test and post-test exercises. From Tables 8 to 14 and from Figures 3 to 13 are the results that were used to answer the research questions, while Table 15 addressed the research hypotheses.

4.1.1 Research Question One: *What is the nature of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?*

This research question sought to determine the nature of explanations of the pre-service science teachers prior to being introduced to the POE model-based teaching and learning strategy. Nature of students' explanations to concepts in the pre-test items was distributed under four categories of nature of scientific explanation: everyday explanation, descriptive explanation, causal explanation, and formal explanation.

The results of the descriptive analysis conducted on students' answers to the pre-test items are presented in Table 8. The number of responses (n) and the corresponding percentages

(%) recorded in each category outlined for categorising nature of an explanation for all the Pre-tests were indicated.

Table 8: Distribution of nature of participants' explanations to concepts in the Pre-tests

Nature of Explanation	Pre-test 1 n (%)	Pre-test 2 n (%)	Pre-test 3 n (%)	Pre-test 4 n (%)	Pre-test 5 n (%)
Everyday Explanation	13 (17.8)	14(19.2)	21 (28.8)	11 (15.1)	12 (16.4)
Descriptive Explanation	41 (56.2)	28 (38.4)	31 (42.5)	21 (28.8)	32 (43.8)
Causal Explanation	18 (24.7)	23 (31.5)	18 (24.7)	35 (47.9)	24 (32.9)
Formal Explanation	1 (1.4)	8 (11.0)	3 (4.1)	6 (8.2)	5 (6.8)
Total	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)

n = number of responses

Table 8 depicts the results on the nature of the students' explanations to concepts in all five (5) Pre-test lessons of the study. In Pre-test 1, thirteen (13) participants representing 17.8% gave their explanations to the concepts using everyday explanations. More than half of the participants, 41 (56.2%) also gave descriptive explanations, with 18 (24.7%) of them offering causal explanation. One participant (1.4%) was able to give formal explanation to those concepts in Pre-test 1. Thus, over 75% of total answers were in the everyday and descriptive explanations, leaving just about a quarter of answers in the causal and formal explanations.

A similar trend was observed in Pre-test 2 concepts where majority of the students continued to provide answers largely falling in the everyday and descriptive explanations than in the causal and formal explanations. Fourteen (14) participants representing 19.2% and 28 (38.4%) presented their answers in the form of everyday and descriptive explanations respectively, while 23 (31.5%) and 8 (11.0%) gave causal and formal explanations to the concepts respectively. Again, for the concepts in Pre-test 2, majority of the responses were in the descriptive explanation category.

Concepts in Pre-test 3 had the highest number of responses in the form of everyday explanations among all the five tests with 21 (28.8%) responses. Thirty-one (31) explanations representing 42.5% were found to be descriptive in nature, with 18 (24.7%) and 3 (4.1%) explanations being causal and formal in nature respectively.

The trend of responses from the participants slightly changed in the Pre-test 4. Causal explanations recorded the highest number of responses with 35 (47.9%) falling into the category. Twenty-one (21) explanations being 28.8% were descriptive in nature, while 11 (15.1%) responses were categorised as everyday explanations. Formal explanation recorded the least number of responses in Pre-test 4 with only 6 (8.2%) answers.

In Pre-test 5, there were 12 (16.4%) responses in the everyday category, 32 (43.8%) in the descriptive category, 24 (32.9%) in the causal category, and only 5 responses being 6.8% recorded in the formal category.

Conclusively, a careful examination of the results from Table 8 revealed the different types of explanations provided by the pre-service science teachers in the Pre-tests (Pre-test 1, Pre-test 2, Pre-test 3, Pre-test 4, and Pre-test 5). Averagely, there were 14.2 (19.5 %) everyday explanations, 30.6 (42.0 %) descriptive explanations, 23.6 (32.3 %) causal explanations and 4.6 (6.3%) formal explanations. Thus, the number of participants who provided formal explanations was the lowest across all Pre-tests, with less than 10% of participants providing formal explanations. However, a majority of the explanations were descriptive in nature.

For a better visual representation of the results in Table 8, the responses for all five Pre-tests were further plotted into a graph as shown in Figure 3.

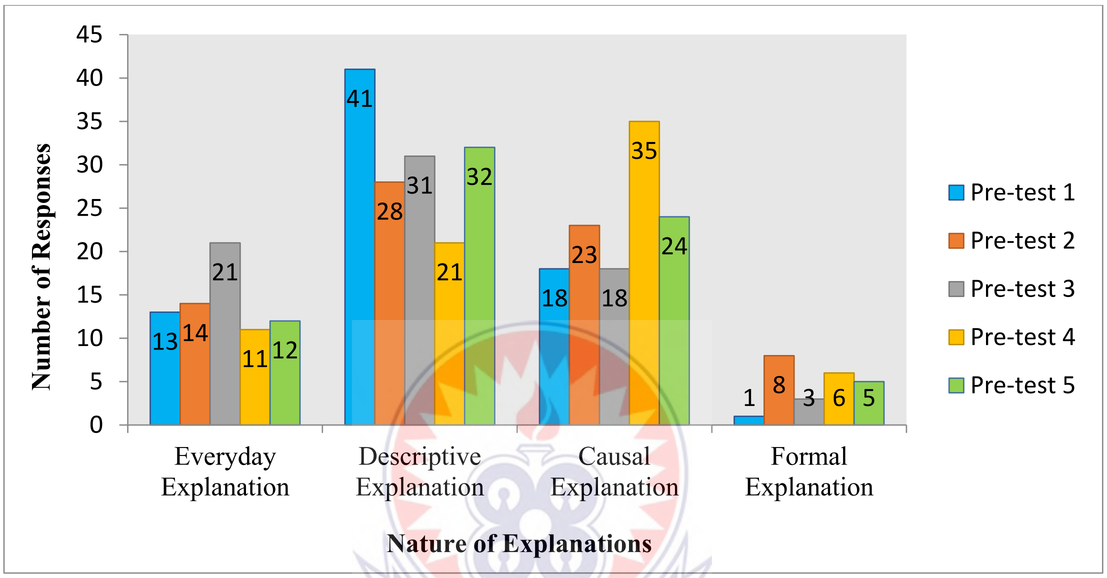


Figure 3: Distribution of nature of participants' explanations in the Pre-tests

Figure 3 visually shows the distribution of the nature of students' responses to the five Pre-tests for the study. From the graph, descriptive explanations have the highest counts throughout the tests, except Pre-test 4. However, there is a decrease in the proportion of participants providing descriptive explanations from Pre-test 1 to Pre-test 4, followed by an increase in Pre-test 5. Conversely, there is an increase in the proportion of participants providing causal explanations from Pre-test 1 to Pre-test 4, followed by a decrease in Pre-test 5. A striking feature is that the proportion of participants providing formal explanations remained consistently low throughout all the Pre-tests.

The average number and percentages of responses for each categorisation of explanation for all the Pre-tests was determined as indicated in Figure 4.

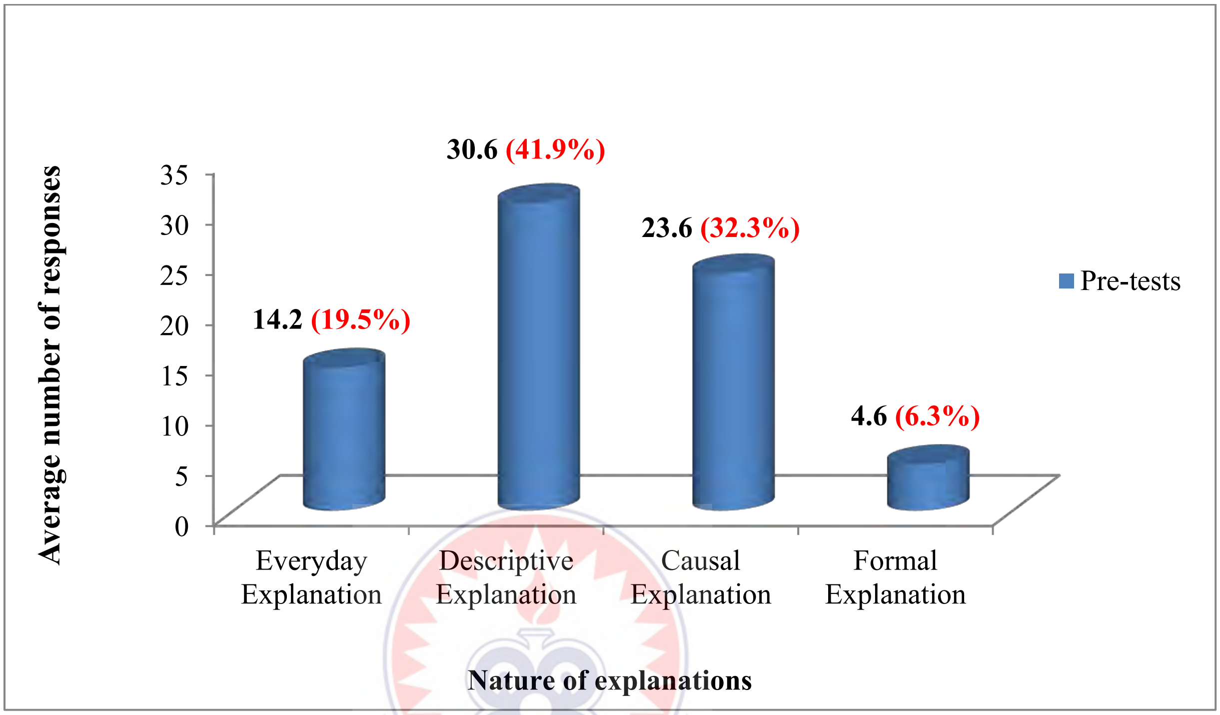


Figure 4: Distribution of average number of responses for nature of explanations in the Pre-tests

Figure 4 revealed that during the Pre-tests, the category of explanations with the highest average number of responses was descriptive explanation with 30.6 responses (41.9%). This was followed by causal explanation indicating an average of 23.6 (32.3%) and everyday explanation with 14.2 (19.5%). The category of formal explanation had the lowest number 4.6 average responses indicating 6.3%.

4.1.2 Research Question Two: *What is the nature of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?*

Research question two aimed to investigate the nature of scientific explanations provided by pre-service teachers to concepts in science after using the POE (Predict-Observe-Explain) model-based interactive teaching approach. This was to determine whether there were any changes to the nature of the explanations they gave to concepts after encountering the POE model-based strategy. Nature of explanations was categorised into everyday explanation, descriptive explanation, causal explanation, and formal explanation.

The results of the study were recorded in Table 9, which shows the number and percentage of distribution of the responses given by participants across five post-tests concepts. The number of responses (n) for each test and the corresponding percentages (%) were determined using descriptive analysis.

Table 9: Distribution of nature of participants' explanations to concepts in the Post-tests

Nature of Explanation	Post-test 1 (%)	Post-test 2 (%)	Post-test 3 (%)	Post-test 4 (%)	Post-test 5 (%)
Everyday Explanation	1 (1.4)	1 (1.4)	0 (0)	0 (0)	0 (0)
Descriptive Explanation	19 (26.0)	16 (21.9)	3 (4.1)	4 (5.5)	0 (0)
Causal Explanation	40 (54.8)	35 (47.9)	34 (46.6)	23 (31.5)	26 (35.6)
Formal Explanation	13 (17.8)	21 (28.8)	36 (49.3)	46 (63.0)	47 (64.4)
Total	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)

n = number of responses

Table 9 displays the students' results with regard to the nature of their explanation to concepts in the five (5) Post-tests of the study. For Post-test 1, majority of the responses, 40 (54.8%) gave causal explanation to concepts and only 1 (1.4%) responded using everyday explanation. There were 19 (26.0%) participants who answered using descriptive explanation and 13 participants representing 17.8% explained concepts using formal explanation.

In Post-test 2, only 1 participant representing 1.4% of the respondents used everyday explanation to give meaning to concepts, just as in Post-test 1. Responses that were of causal explanation came from 35 (47.9%) of participants, while formal explanations increased to 21 (28.8%) from the 13 recorded in Post-test 1. Sixteen (16) explanations indicating 21.9% of the participants explained concepts using descriptive explanations. Data from Post-test 3 showed that none of the participants responded using everyday explanation, and quite a few (3) representing 4.1% gave descriptive explanations to concepts. Almost half of the responses from the participants (49.3%) fell in the category of formal explanation and 46.6% of them gave their answers using causal explanation.

The results from Post-test 4 clearly show that there was no answer given using everyday explanation and only 4 (5.5%) explanations were in the descriptive category. A chunk of the participants 46 (63.0%) used formal explanation to give meaning to concepts. Again, 21 participants, making 31.5% explained concepts by applying causal explanation. In the last Post-test there were only two categories of explanations given by the participants, and they were 26 (35.6%) and 47 (64.4%) for causal and formal explanations respectively. None of the explanations from the students fell into the categories of everyday and descriptive.

In overall, the results showed that the majority of the pre-service teachers provided causal and formal explanations to concepts in their Post-tests, while only a few provided everyday explanations. In particular, the percentage of causal explanations provided by the pre-service teachers declined over the course of the Post-tests, with the highest percentage being in Post-test 1 (54.8%) and the lowest being in Post-test 4 (31.5%). On the other hand, the percentage of formal explanations increased steadily over the course of the Post-tests, with the lowest percentage being in Post-test 1 (17.8%) and the highest being in Post-test 5 (64.4%). Again, the results indicate a decrease in the percentage of descriptive explanations, with the highest percentage being in Post-test 1 (26.0%) and the lowest being in Post-test 5 (0%).

The results in Table 9 are further presented in Figure 5 to give a better visualisation of the nature of the participants' explanations to concepts in the post-tests.

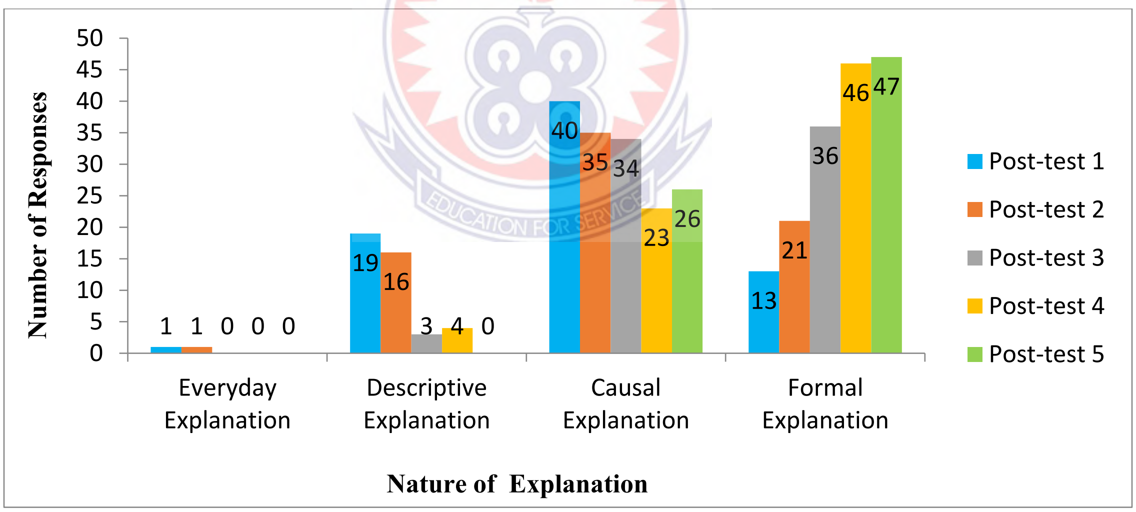


Figure 5: Distribution of nature of participants' explanations in the Post-tests

Figure 5 gives a graphical view of the nature of the pre-service teachers' explanations to concepts in Heat and Thermodynamics within the five Post-tests. The distribution of the nature of explanations varied across the Post-tests. In Post-tests 1 and 2, causal explanation was the dominant category, followed by descriptive explanation and formal explanation.

However, in Post-tests 3, 4, and 5, formal explanation emerged as the predominant category, with causal explanation being the second most common. The percentage of everyday explanation remained consistently low throughout all Post-tests.

To further provide details on the nature of the participants' explanations to concepts in the Post-tests, the average value for each category of explanation as well as its corresponding percentage was determined using data from Table 9. The result of the analysis is shown in Figure 6.

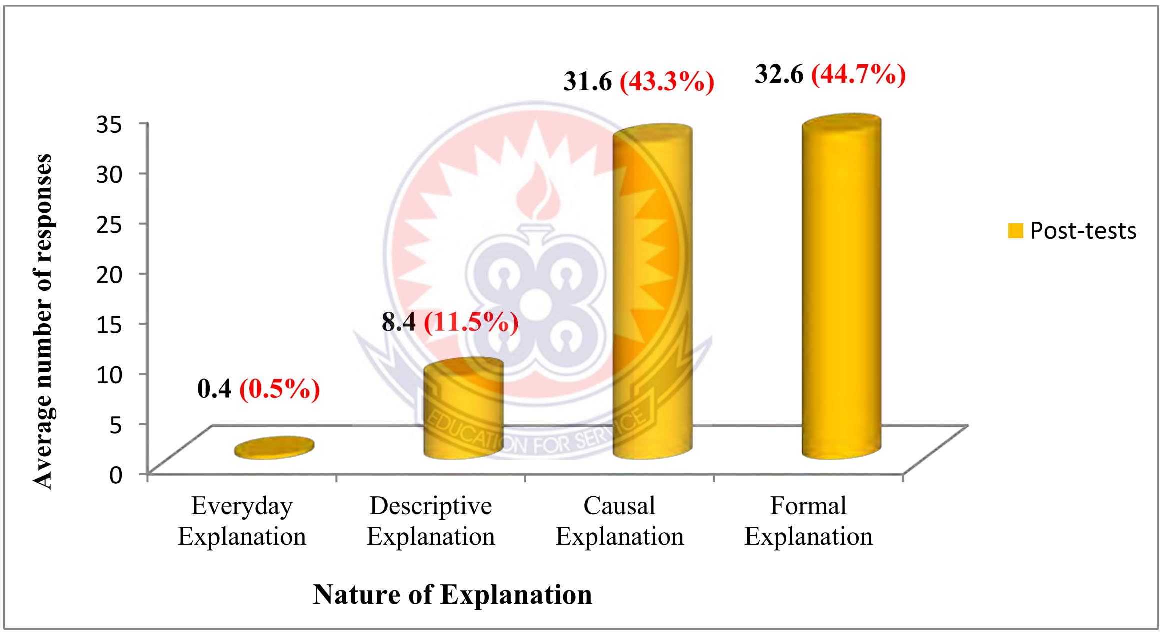


Figure 6: Distribution of average number of responses for nature of explanations in the Post-tests

In Figure 6, the average number of responses for all the categories of nature of explanation for the five Post-tests was displayed. The category of formal explanation had the highest number of 32.6 responses indicating 44.7%. This was followed by causal explanation with 31.6 (43.3%) responses and descriptive explanations with 8.4 (11.5%) responses. The average responses for everyday explanation were the least with 0.4 responses indicating 0.5%.

4.1.3 Research Question Three: *What is the quality of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?*

To help answer research question three (3), the quality of the pre-service teachers' explanations to the various concepts as indicated in their responses to the concepts in the Post-tests was analysed. The responses were subjected to descriptive statistical analysis for their categorisation distinguishing the levels of scientific reasoning and accuracy, outlined in Table 3. Data gathered from the analysis is presented in Table 10.

Table 10: Distribution of quality of participants' explanations to concepts in the Pre-tests

Quality of Explanation	Pre-test 1 n (%)	Pre-test 2 n (%)	Pre-test 3 n (%)	Pre-test 4 n (%)	Pre-test 5 n (%)
Wrong Explanation	27 (37.0)	23 (31.5)	22 (30.1)	25 (34.2)	18 (24.7)
Partial Explanation	43 (58.9)	41 (56.2)	37 (50.7)	32 (43.8)	36 (49.3)
Sound Explanation	3 (4.1)	9 (12.3)	14 (19.2)	16 (21.9)	19 (26.0)
Total	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)

n = number of responses

Data from Table 10 displays the results of all five Pre-tests for the study, indicating the number of responses and how they are distributed among the categories of quality of explanations. There was a total number of 73 participants for each test.

In Pre-test 1, there were 27 (37%) explanations which were in the wrong explanation category, with 43 (58.9%) of them being partial explanations. Only 3 (4.1%) responses were categorised as sound explanations. A similar trend in quality of explanations was observed in the second Pre-test concepts.

In the Pre-test 2, majority of the responses 41 (52.6%) were partial explanations, 23 of the responses representing 31.5% were wrong explanations, while 9 responses representing 12.3% were sound explanations. In the Pre-test 3, the number of explanations classified as wrong were 22 (30.1%), with 37 responses representing 50.7% being partial explanations. Explanations categorised as sound were 14 (19.2%).

There were 25 (34.2%) responses in Pre-test 4 that were wrong explanations, 32 (43.8%) responses classified as partial explanations, and 16 (21.9%) responses were deemed to be sound explanations. A similar trend in scientific explanation was observed in Pretest 5 with 18 (24.7%) responses considered as wrong explanations, 36 (49.3%) and 19 (26%) responses being partial and sound explanations respectively. Therefore, averagely, of all the five Pre-tests, only 12 (16.7%) responses were sound in their explanations, with a majority of the explanations (61) representing 83.3% being wrong and/or partial.

The results of the quality of the scientific explanations through students' responses in Table 10 have been graphically presented in Figure 7.

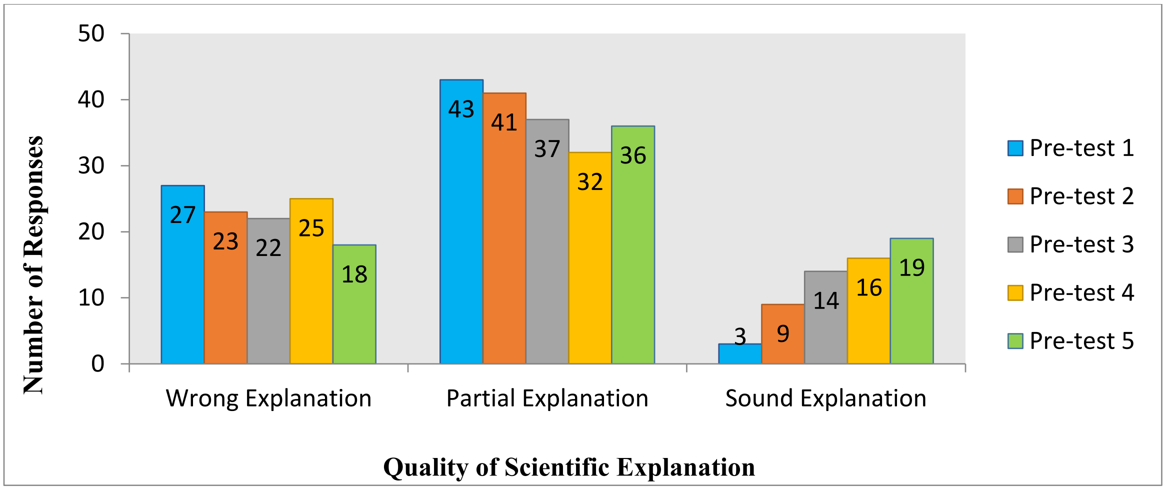


Figure 7: Distribution of quality of participants' explanations in the Pre-tests

Figure 7 gives a visual representation of the data in Table 10, showing how the quality of the students' responses was distributed among the categories for all the five Pre-tests. Partial explanations were predominantly high among all the responses. However, it showed a decreasing trend from Pre-test 1 to Pre-test 4 followed by an increase in Pre-test 5. Wrong explanations were the second highest with a fluctuating trend over the Pre-tests. The category with the least number of responses was sound explanation, but it demonstrated a consistent increase in percentages across the Pre-tests. The percentage of wrong explanations ranged from 24.7% to 37.0%, partial explanations ranged from 43.8% to 58.9% with sound explanations also ranging from 4.1% to 26.0% across the five Pre-tests. Hence, the graph revealed that in overall, majority of students' explanations fell in the wrong and partial classifications, with only a few being classified as sound.

The average number of responses and corresponding percentages for each category of quality of explanation was determined to provide a useful summary and an overall perspective on the distribution of responses across the Pre-tests. This also allowed for easy comparison between the different categories, and the result of the analysis is presented in Figure 8.

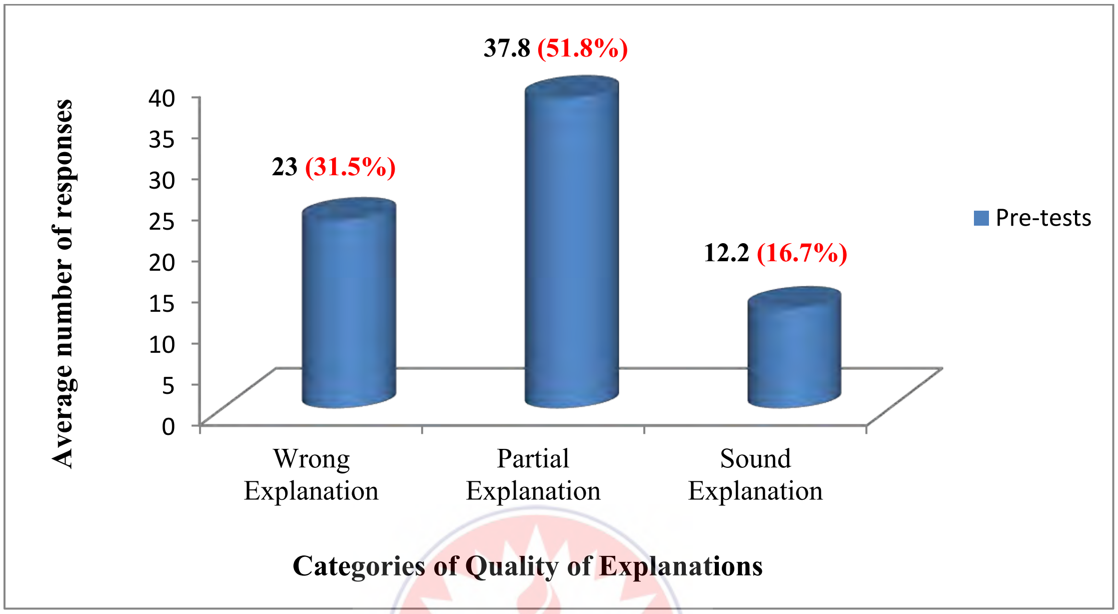


Figure 8: Distribution of average number of responses for quality of explanations in the Pre-tests

The average number of responses and the corresponding percentages for each category of quality of explanation across the Pre-tests are shown in Figure 8. The Figure indicates that on average, the majority (51.8%) of explanations fell into the category of partial explanation, followed by wrong explanation with 31.5%, while sound explanation had the lowest average percentage of 16.7%.

4.1.4 Research Question Four: *What is the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?*

This question sought to determine the level of scientific reasoning as well as the scientific accuracy (quality) of the students' explanations to concepts after exposure to the POE model-based interactive teaching strategy. Hence students' responses offered to explain concepts in the Post-tests were classified into wrong, partial or sound explanations based on depth of reasoning and accuracy. Results from the Post-tests are presented in Table 11.

Table 11: Distribution of quality of participants' explanations to concepts in the Post-tests

Quality of Explanation	Post-test 1 n (%)	Post-test 2 n (%)	Post-test 3 n (%)	Post-test 4 n (%)	Post-test 5 n (%)
Wrong Explanation	5 (6.8)	2 (2.7)	0 (0)	0 (0)	0 (0)
Partial Explanation	7 (9.6)	17 (23.3)	3 (4.1)	2 (2.7)	2 (2.7)
Sound Explanation	61 (83.6)	54 (74.0)	70 (95.9)	71 (97.3)	71 (97.3)
Total	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)	73 (100.0)

n = number of responses

Results from Table 11 indicate the distribution of the students' responses to the Post-test questions regarding the quality of the explanations. Post-test 1 had 61 (83.6%) out of the responses being classified as sound explanations, while partial and wrong explanations received 7 (9.6%) and 5 (6.8%) of the responses respectively. In the Post-test 2 concepts, there were only 2 (2.7%) responses deemed as wrong explanations, 17 (23.3%) of the responses were partial explanations and a majority of responses 54 (74.0%) were considered sound explanations.

Concepts in Post-tests 3, 4 and 5 received no wrong responses (0%) for all three tests. For partial explanations, Post-test 3 had 3 (4.1%) of the responses while both Post-tests 4 and 5 had the same number of responses 2 (2.7%) each. All three tests had the highest number of responses considered as sound explanations with 70 (95.9%), 71 (97.3%) and 71 (97.3%) respectively. Considering the average results over the five Post-tests, it was revealed that only 1 response representing 1.9 % was categorised as wrong explanation, 6 (8.5%)

responses were considered partial explanations while 65 (89.6%) explanations were categorised as sound.

The results of the quality of the scientific explanations through students' responses in Table 11 have been graphically presented in Figure 9.

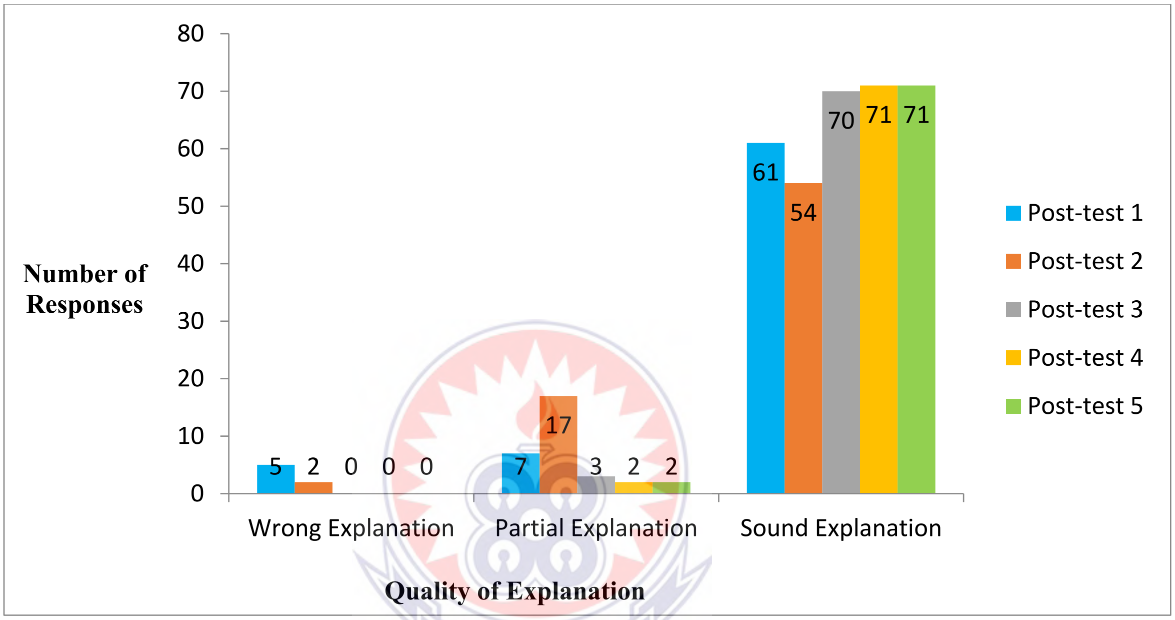


Figure 9: Distribution of quality of participants' explanations in the Post-tests

An examination of the graph in Figure 9 reveals how the quality of the pre-service teachers' responses to the five Post-tests was distributed among the categories of quality of explanation. Wrong explanation received the least number of responses, and showed a decreasing pattern over the five Post-tests. There was a decline in the number of wrong explanation in Post-tests 1 and 2, and then a complete absence from Post-tests 3 to 5. Partial explanation showed an increasing trend in the number of responses from Post-test 1 to Post-test 2, but decreased from Post-test 2 to Post-test 3, and remained constant for Post-tests 4 and 5. Sound Explanation had a consistent increase in the number of responses over the five Post-tests, with the number steadily rising and remaining high in Post-tests 3, 4, and 5.

To obtain a visual perspective of each category of explanation, and allow for easy comparison among them, the average number and corresponding percentages of responses to each category was determined. The result is shown in Figure 10.

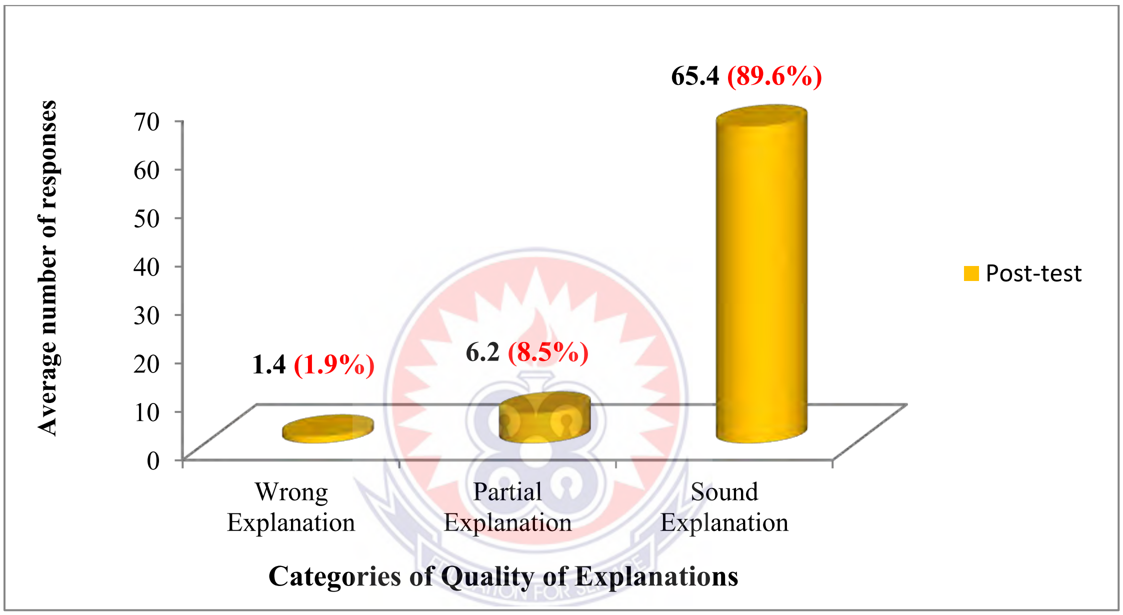


Figure 10: Distribution of average number of responses for quality of explanations in the Post-tests

Figure 10 reveals the average number of responses and the percentages for each category of explanation pertaining to the quality of an explanation. A greater percentage of all the responses were in sound explanation with 65.4 representing 89.6%. Partial and wrong explanation categories had quite low responses indicating 6.2 (8.5%) and 1.4 (1.9%) respectively.

4.1.5 Research Question Five: ***How do pre-service teachers perceive the use of the POE model-based interactive teaching of concepts in science?***

The students' responses to the statements in the questionnaire were assessed to determine their perceptions towards the use of the POE model-based teaching strategy in the study of the various concepts in Heat and Thermodynamics. Students' perceptions were analysed in terms of how they perceived the use of the POE during their study cognitively (on their conceptual learning of science), behaviourally (on their attitudes towards science) and emotionally (on their interests and motivations in the study of science).

Firstly, four items on the questionnaire which were themed as cognitive perceptions were analysed to determine how they impacted the students' conceptual learning of the science concepts. The items are as follows:

- *The POE model based teaching and learning helped me become aware of the importance of science involved in my daily life.*
- *The POE model based teaching and learning made my understanding of science concepts easier.*
- *The POE model based teaching and learning did not confuse me in the course of study.*
- *Through the POE model based teaching and learning I was able to relate content taught to everyday life.*

The distribution of students' responses to the items (n), and their corresponding percentages (%) concerning their cognitive perceptions are indicated in Table 12.

Table 12: Distribution of students' responses to items on cognitive perceptions of the POE model

Items on Cognitive Perceptions of POE Model	Strongly Agree n (%)	Agree n (%)	Neutral n (%)	Disagree n (%)	Strongly Disagree n (%)	Total n (%)
Awareness of importance of Science	146 (58.4)	80 (32.0)	19 (7.6)	5 (2.0)	0 (0.0)	250 (100.0)
Understanding of science concepts made easier	110 (44.0)	102 (40.8)	25 (10.0)	9 (3.6)	4 (1.6)	250 (100.0)
Not confused during lessons	99 (39.9)	120 (48.4)	20 (8.1)	7 (2.8)	2 (0.8)	248 (100.0)
Relating concepts to daily life	133 (53.2)	94 (37.6)	17 (6.8)	3 (1.2)	3 (1.2)	250 (100.0)

Table 12 reveals the distribution of the pre-service students' responses to the items related to their perceptions of the use of the POE model-based teaching strategy on their cognitive processes. That is, how they perceived the teaching strategy on their way of learning the concepts of Heat and Thermodynamics.

On their awareness of the importance of science to daily life, 146 (58.4%) and 80 (32.0%) students out of a total of 250 strongly agreed and agreed respectively to the statement. While 19 (7.6%) students neither agreed nor disagreed, 5 (2.0%) students disagreed to the item and none (0.0%) strongly disagreed. The item on how the POE made their understanding of science concepts easier, majority of the students (212) representing 84.4% strongly and/or agreed to the statement, while 13 (5.2%) students disagreed. Students who remained neutral about the statement were 25 representing 10.0%. Students who strongly agreed and agreed to not being confused during the POE lessons were 99 (39.9%) and 120 (48.4%) respectively, out of 248 responses. 20 students (8.1%) neither agreed nor disagreed to the statement, 7 (2.8%) disagreed and 2 (0.8%) strongly disagreed. The statement about the ability of the students to relate concepts taught to daily life through the use of the POE model based teaching strategy elicited the following responses: 133 (53.2%) strongly agreed, 94 (27.6%) agreed, 17 (6.8%) were neutral, 3 (1.2%) disagreed and 3 (1.2%) strongly disagreed.

Data from Table 12 was transformed into a chart in Figure 11 to enable easy visualisation and analysis of the statistics.

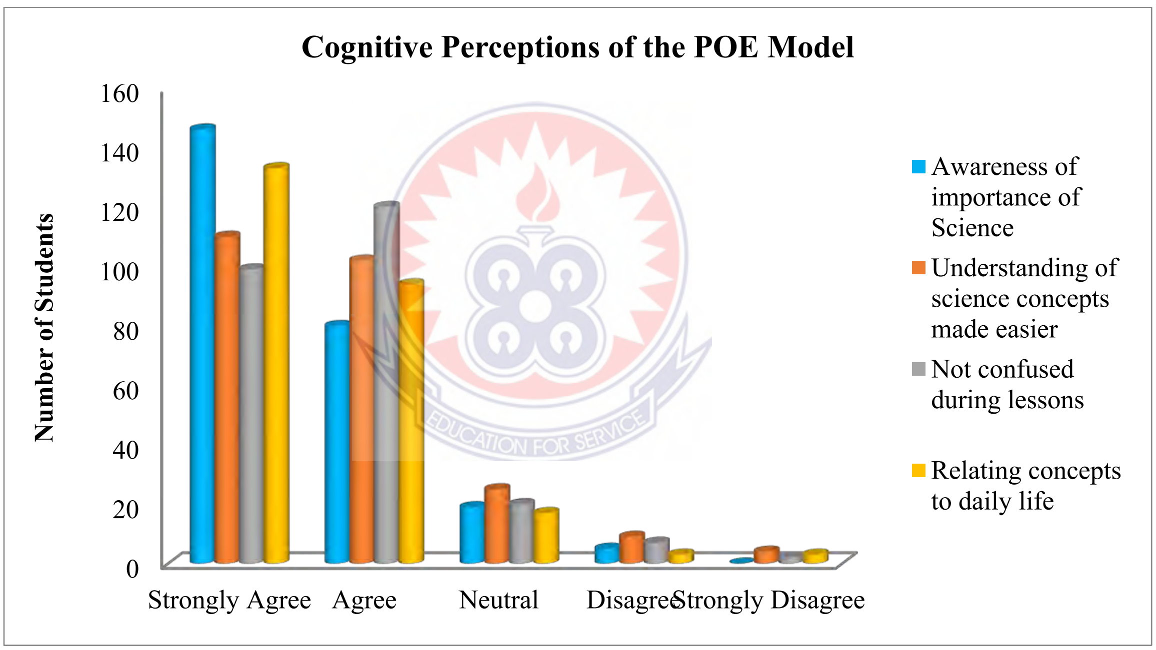


Figure 11: Distribution of students' responses to their cognitive perceptions of the POE model-based strategy

Data from Figure 11 indicates the trend of the students' responses to the questionnaire items pertaining to how they perceived the effect of the POE model-based strategy on their conceptual learning of the science concepts. From the graph, it is revealed that overall, majority of the students' responses to the items were in the ranges of strongly agree and agree. However, the item 'awareness of the importance of science' had the highest number of students (58.4%) strongly agreeing, and no student (0%) strongly disagreeing to it.

Secondly, the items on the questionnaire which pertained to the students' perceptions of their attitudes towards the study of the science concepts were assessed and analysed. These items, all themed as behavioural perceptions towards the use of the POE model-based teaching strategy are as listed below:

- *The POE model based teaching and learning made me prepare before coming to class by doing the pre-reading assignments.*
- *The POE model based teaching and learning made me change my behaviour during class in a more positive way.*
- *Through the POE model based teaching and learning I learnt from my colleagues.*
- *The POE model based teaching and learning made me more engaged with my classmates.*

The pre-service teachers' responses to these four items are indicated in Table 13, revealing the distribution of their responses to each item.

Table 13: Distribution of students' responses to items on behavioural perceptions of the POE model

Items on Behavioural Perceptions of POE the Model	Strongly Agree n (%)	Agree n (%)	Neutral n (%)	Disagree n (%)	Strongly Disagree n (%)	Total n (%)
Prepared before attending classes	140 (56.2)	81(32.5)	20 (8.0)	5 (2.0)	3 (1.2)	249 (100.0)
Positive change in behaviour	139 (55.8)	86 (34.5)	20 (8.0)	1(0.4)	3 (1.2)	249 (100.0)
Learning from colleagues	107(43.0)	101(40.6)	26 (10.4)	10 (4.0)	5 (2.0)	249 (100.0)
Enhanced interactions with colleagues	162 (65.1)	66 (26.5)	15(6.0)	5 (2.0)	1(0.4)	249 (100.0)

Data from Table 13 reflects how the pre-service teachers responded to the four items relating to their perceptions of the POE model-based strategy on their behaviour (attitudes towards science learning).

Responding to the statement about the use of the POE in making them prepare before attending classes, out of a total of 249 respondents, majority (140) representing 56.2% strongly agreed to the statement. The numbers of students that agreed to the statement were 81 (32.5%), with 5 (2.0%) and 3 (1.2%) students responding disagree and strongly disagree respectively. 20 students (8.0%) were neutral about the statement. The second item elicited the students' perceptions about the use of the POE model in positively changing their behaviour (attitude) in class. To this item, 139 (55.8%) students strongly agreed to the statement, 86 (34.5%) agreed, 20 (8.0%) were neutral in their response, 1 (0.4%) disagreed and 3 (1.2%) strongly disagreed. The next item sought to determine their perceptions about learning from their colleagues as a result of the use of the POE model-based strategy. A majority of 107 (43.0%) responses out of the 249 responses strongly agreed to the statement while 101 (40.6%) agreed, and 26 (10.4%) remained neutral. 10 (4.0%) responses disagreed and 5 (2.0%) strongly disagreed. A similar trend of responses was observed in the last item which assessed the students' perceptions on how the POE model-based strategy enhanced their engagements with each other. 162 (65.1%) responses indicated a strong agreement with the statement, with 66 (26.5%) responding agreed, 15 (6.0%) neither agreed nor disagreed, 5 (2.0%) disagreed and 1 (0.4%) strongly disagreed.

To obtain a visual representation of the data in Table 13, the statistics were transformed into a graph, as shown in Figure 12.

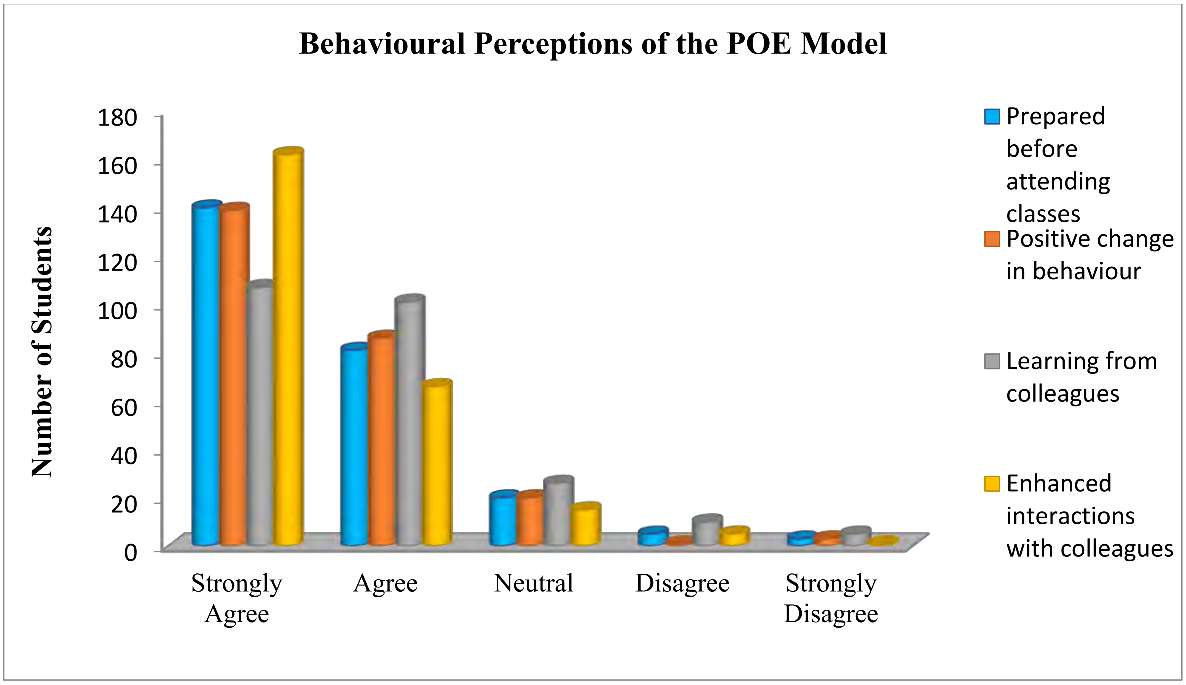


Figure 12: Distribution of students' responses to their behavioural perceptions of the POE model-based strategy

The graph in Figure 12 reveals that majority of all the responses to the four coded items were in the strongly agree to agree ranges of the Likert scale. Strikingly, of all the responses to the items, the students' perceptions of their enhanced engagements with their colleagues were highly rated above all the others, receiving the highest number of strongly agree responses (65.1%) and the lowest number of strongly disagree responses (0.4%).

Lastly, the students' perceptions on the use of the POE model-based teaching strategy towards their interests and motivations (emotional perceptions) in their study of the science concepts were assessed and analysed. To determine how the pre-service teachers perceived the use of the model with regards to their emotional perceptions (interests and motivation) during the period of the study, their responses to five items of the questionnaire coded as emotional themes were assessed. The items are indicated below:

- *The POE model based teaching and learning did not make me feel discouraged during science lessons.*
- *The POE model based teaching and learning made me more enthused about studying science.*
- *The POE model based teaching and learning has influenced my perception of science in a positive way.*
- *The POE model based teaching and learning made the learning of science fun.*
- *The POE model based teaching and learning made learning tedious for me.*

The results of the analysis of the students' responses to these items are as shown in Table 14.

Table 14: Distribution of students' responses to items on emotional perceptions of the POE model

Items on Emotional Perceptions of POE the Model	Strongly Agree n (%)	Agree n (%)	Neutral n (%)	Disagree n (%)	Strongly Disagree n (%)	Total n (%)
Not discouraged in studying science	96 (38.4)	115 (46.0)	29 (11.6)	6 (2.4)	4 (1.6)	250 (100.0)
Enthused about studying science concepts	120 (48.2)	96 (38.6)	26 (10.4)	5 (2.0)	2 (0.8)	249 (100.0)
Positive influence in perception	136 (54.4)	88 (35.2)	21 (8.4)	3 (1.2)	2 (0.8)	250 (100.0)
Learning of science made fun	49 (19.6)	109 (43.6)	56 (22.4)	29 (11.6)	7 (2.8)	250 (100.0)
Learning of science tedious	14 (5.6)	36 (14.5)	29 (11.6)	86 (34.5)	84 (33.7)	249 (100.0)

Table 14 revealed that out of a total of 250 responses to statement that the use of the POE model-based strategy did not confuse them in their study of the science concepts, 96 (38.4%) strongly agreed. This was followed by 115 (46.0%) students also agreeing to the statement. However, 29 (11.6%) students neither agreed nor disagreed to the statement, while 6 (2.4%) and 4 (1.6%) students disagreed and strongly disagreed respectively to the statement. Again, out of the 249 responses, 120 (48.2%) respondents strongly agreed that they were enthused about their study of the science concepts, 96 (38.6%) also agreed, and 26 (10.4%) neither agreed nor disagreed. 5 (2.0%) and 2 (0.8%) students disagreed and strongly disagreed respectively to being enthused about their study of science. The statement on how the POE model-based strategy had positively influenced their perceptions of science saw a majority of the 136 respondents representing 54.4% falling in the scale of strongly agree. Also, 88 (35.2%) respondents agreed, 21 (8.4%) remained neutral, 3 (1.2%) disagreed and 2 (0.8%) strongly disagreed to the statement. 49 (19.6%) out of 250 students strongly agreed that through the use of the POE model their science learning was made fun, while 109 (43.6%) also agreed to the statement, with 56 (22.4%) remaining neutral. However, 29 (11.6%) students disagreed to the statement and 7 (2.8%) strongly disagreed. On the last item of this category of statements, a majority of 170 (68.2%) students strongly disagreed and/or disagreed that the POE made science learning tedious. This was countered by a total of 50 (20.1%) students who either strongly agreed or agreed that the POE model made science learning tedious. However, 29 (11.6%) students were neutral to the statement.

Data from Table 14 was transformed into a chart in Figure 13 to enable visualisation of the statistics.

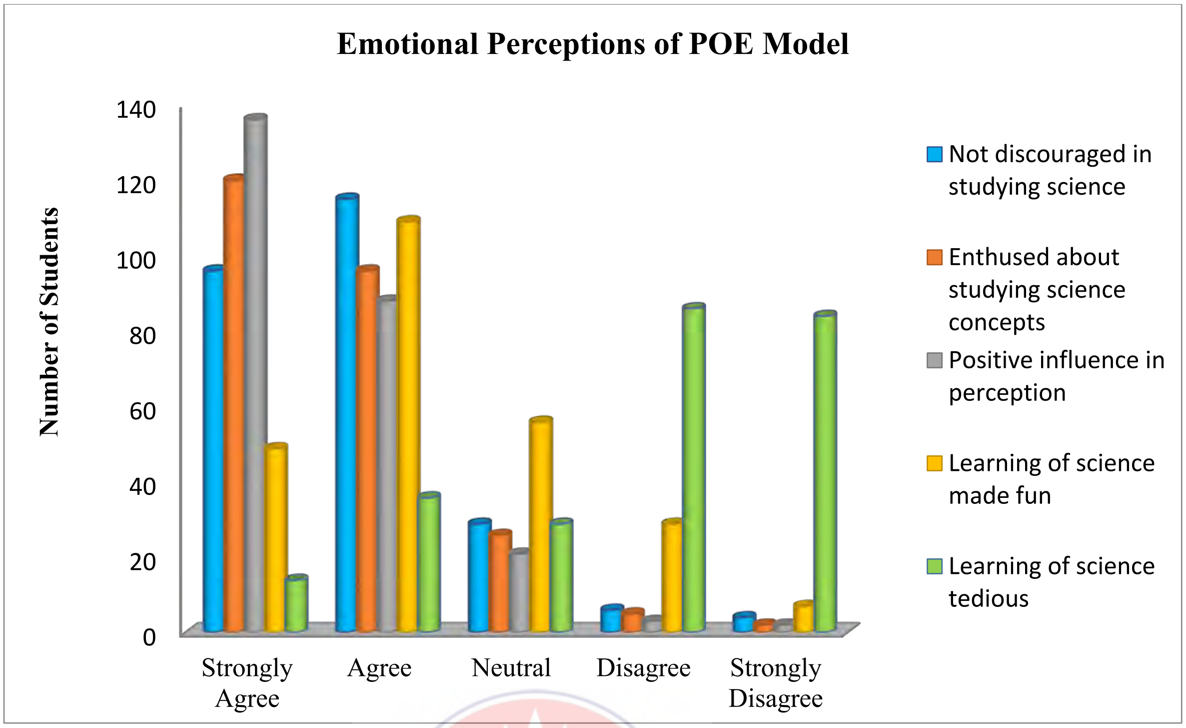


Figure 13: Distribution of students' responses to their emotional perceptions of the POE model-based strategy

From Figure 13, it is clear that although majority of the students' responses to the items were skewed towards strongly agree and agree, the item 'learning of science tedious' was in the opposite. More than half of the students (68.2%) did not think that the POE model made their learning of science tedious. Further, the graph reveals that a greater number of the respondents strongly agreed that the POE model had influenced their perceptions of science positively.

4.1.6 Research Question Six: ***What is the difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science?***

This study intended to investigate whether there was a significant relationship between gender and the students' perceptions of the POE model-based teaching strategy. The POE model-based teaching strategy as a problem-oriented, inquiry-based approach to science teaching and learning encourages students to engage in active learning by posing questions, making observations, and drawing conclusions. Hence, to determine any significant gender difference in the perceptions of the pre-service teachers towards the use of the POE model-based teaching strategy, a Crosstabulation and chi-square test of the female and male students' perceptions of the use of the POE model-based strategy was carried out. The result of the analysis is presented in Table 15.

Table 15: Crosstabulation with chi-square results of female and male students' perceptions of the POE model-based strategy

	Sex	Perceptions of the POE model-based teaching strategy		Total	χ^2 value	df	Sig. value
		Positive	Negative				
Male	Count	142	60	202	.163[a]	1	.687
	% within Sex	70.3%	29.7%	100.0%			
Female	Count	33	16	49			
	% within Sex	67.3%	32.7%	100.0%			
Total	Count	175	76	251			
	% within Sex	69.7%	30.3%	100.0%			

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.84.

The results from Table 15 depicts that out of the 251 (100%) students who participated in the study, 175 (69.7%) that had positive perceptions towards the POE model-based teaching and learning strategy, while 76 (30.3%) had negative perceptions. Furthermore, 202 (80.5%) were males while 49 (19.5%) were females. Out of the 202 males, 142 (70.3%) had positive perceptions of the POE model-based strategy, while 60 (29.7%) had negative perceptions. On the other hand, out of the 49 females, 33 (67.3%) also had positive perceptions, while 16 (32.7%) had negative perceptions towards the model. Hence, majority of both females and males had positive perceptions towards the use of the POE model-based teaching and learning strategy.

To test the research hypotheses formulated for this study, a Pearson Chi-Square test (χ^2) was conducted at a significance alpha level of 0.05. This was to determine whether a significant difference existed between the females and the males in their perceptions of the POE model-based teaching strategy. The chi-squared (χ^2) value of about 0.163 was obtained, with a degree of freedom (df) of 1 and a significant value (p) of 0.687. Since the significant value obtained was higher than the alpha level ($\chi^2 = 0.687$, $p > 0.05$), it indicated that there was no significant statistical difference between the females and the males in their perceptions of the POE model.

4.2 Summary of the Chapter

This chapter presented the results of the study as obtained from the statistical analysis of the data from the research instruments. The results were presented and analysed in line with the research questions stipulated for the study. For each research question, data from the analyses was presented in tables, which were then transformed into charts for easy visualisation and analysis.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.0 Overview

This chapter discusses in detail the results obtained from the previous chapter and how they shape the outcome of the study, in line with related literature. The discussion is done along the research questions and important inferences made from the discourse.

5.1 Discussion of Results

5.1.1 Discussion of Research Question One:

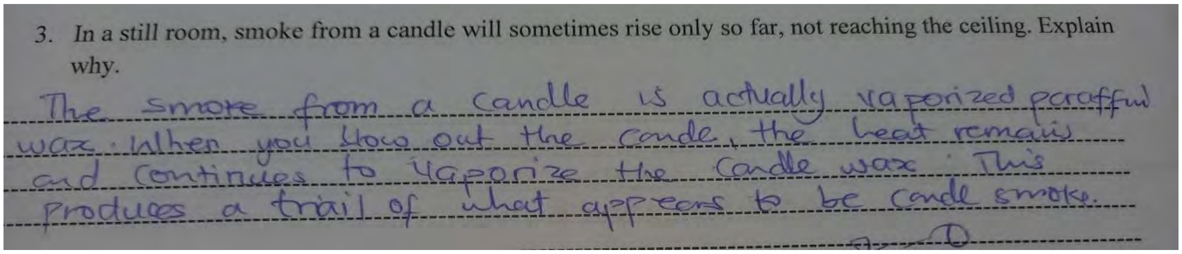
What is the nature of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?

Data from Table 8, Figure 3 and Figure 4 revealed that the pre-service science teachers' explanations were mainly descriptive and ordinary or everyday in nature before the intervention. This suggested that the pre-service teachers approached the learning of the science concepts largely on the basis of their everyday understanding of the phenomena. Majority could not use appropriate scientific language or formal language to express the ideas in the various concepts of the study.

For instance, in Pre-test 5 which dealt with the concept of Heat Transfer (Convection and Radiation), one of the three open-ended questions the pre-service teachers were tasked to answer is stated below.

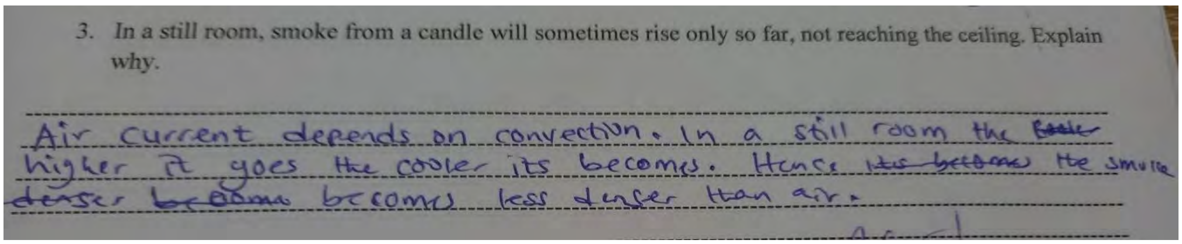
Sample Question 1*: In a still small room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.*

Excerpts of students' responses to the question are presented in the examples below.


3. In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

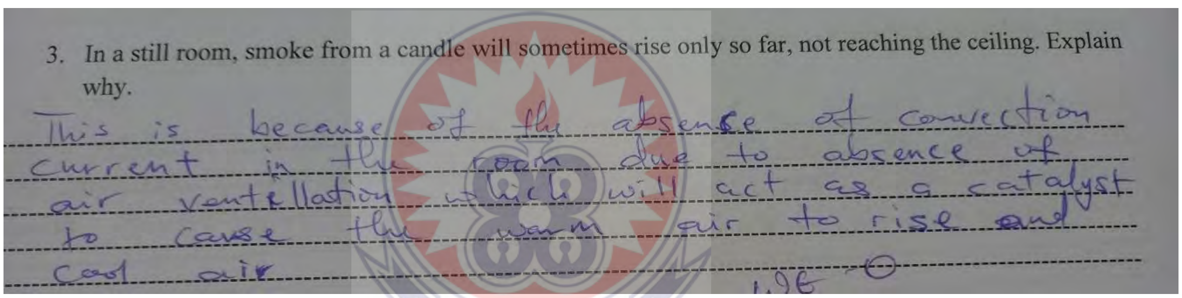
The smoke from a candle is actually vaporized paraffin wax. When you blow out the candle, the heat remains and continues to vaporize the candle wax. This produces a trail of what appears to be candle smoke.

Example 1: Students' sample response one to sample question


3. In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

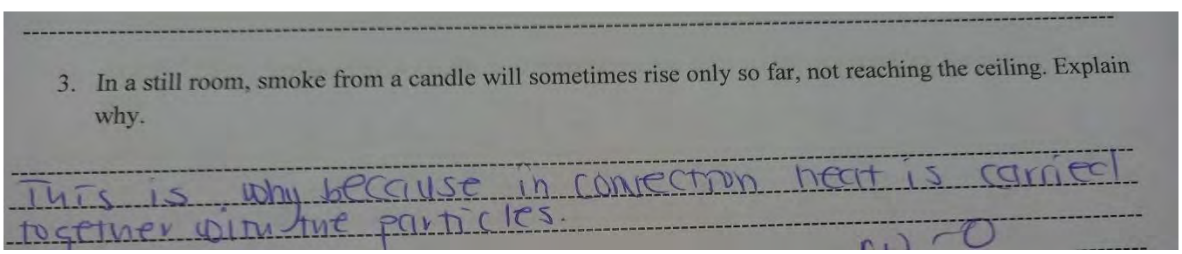
Air current depends on convection. In a still room the higher it goes the cooler its becomes. Hence the smoke becomes less denser than air.

Example 2: Students' sample response two to sample question


3. In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

This is because of the absence of convection current in the room due to absence of air ventillation which will act as a catalyst to cause the warm air to rise and cool air

Example 3: Students' sample response three to sample question


3. In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

This is because in convection heat is carried together with the particles.

Example 4: Students' sample response four to sample question

The sample of responses from Examples 1 to 4 all depicted the use of only suggestive practical knowledge of phenomena of convection currents.

The question tested the students' abilities to explain how convection currents are set up due to temperature differences in a system, as well as how thermal equilibrium in the same system causes the convection currents to cease. However, a greater percentage of the responses (60.2%) were in the everyday and descriptive language. That is, a greater number of the responses could not use formal scientific language to depict correct understanding of the concept, and hence could not explain the scientific bases of the phenomena.

Similarly, in Pre-test 4, on the concept of Heat Transfer (Conduction), a question posed and excerpts of some responses from students are indicated below.

Sample Question 2: *If you hold one end of a piece of metal against a piece of ice, the end in your hand soon becomes cold. Does this mean that cold flows from the ice to your hand? Defend your answer.*

Sample Response 1*: "no, because heat transfer from the hot metal to the ice, because it takes a long time for heat to get to the end of the hand"*

Sample Response 2: *"if we hold one end of the metal nail against a piece of ice the end in your hand will soon become cold"*

Sample Response 3: *"no, heat is transferred from the hand to the ice"*

Sample Response 4: *"as metals drops its temperature, we all start to feel a cold sensation as we begin to exchange heat with the metal"*

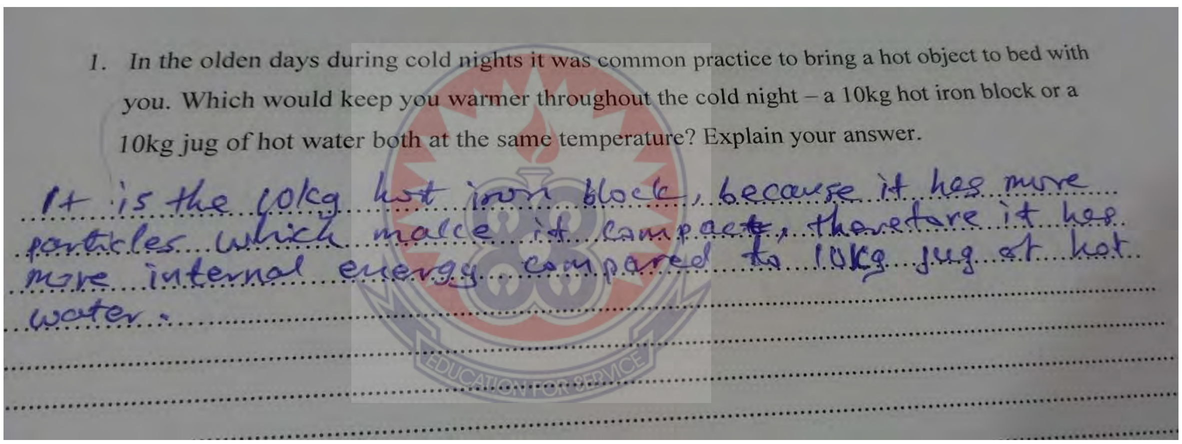
Sample Response 5: *"no, because, the metal absorbed the coldness from the ice which makes the hands to be *colers"*

**colers – this was exactly as written by the respondents.*

Metals being good conductors of heat are able to transfer heat from bodies of higher temperature to bodies of colder temperature easily. Hence, there was the need for the students to establish the fact that the high thermal conducting ability of the metal was the reason for the conduction of heat away from the warm hand causing the hand to lose thermal energy, and as a result feel cold. However, in all of the examples of responses above, the pre-service teachers could not use the formal language of science to describe the phenomenon. Majority used only descriptive and everyday languages to describe the concepts.

Pre-test 3, was on the concept of Specific Heat Capacity, and below are a question posed and samples of responses from the participants.

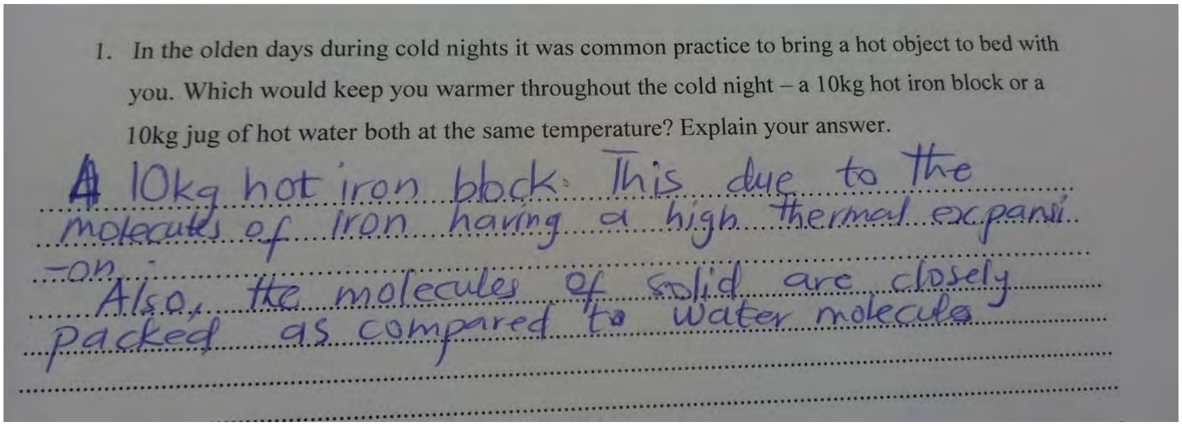
Sample Question 3: *In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.*



1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

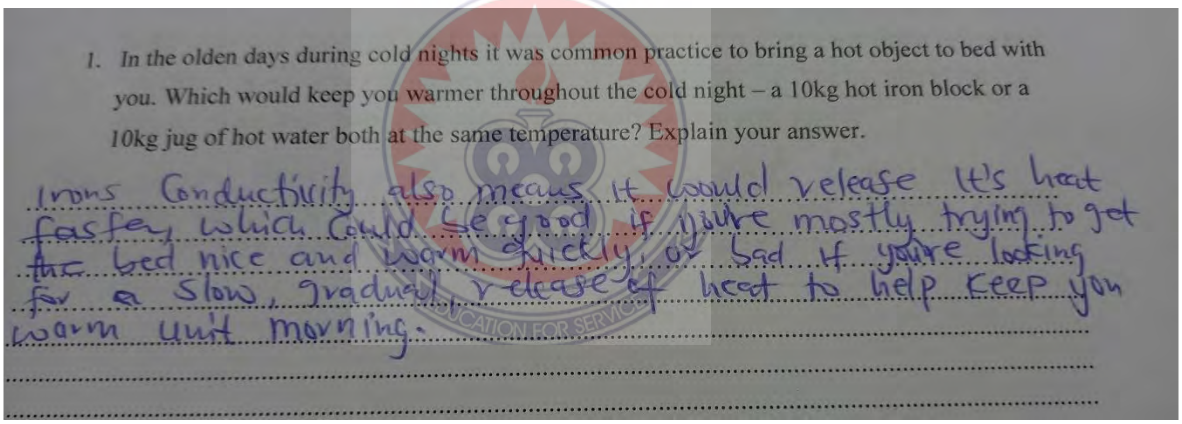
It is the 10kg hot iron block, because it has more particles which make it compact, therefore it has more internal energy compared to 10kg jug of hot water.

Example 5: Students' sample response one to sample question three


1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

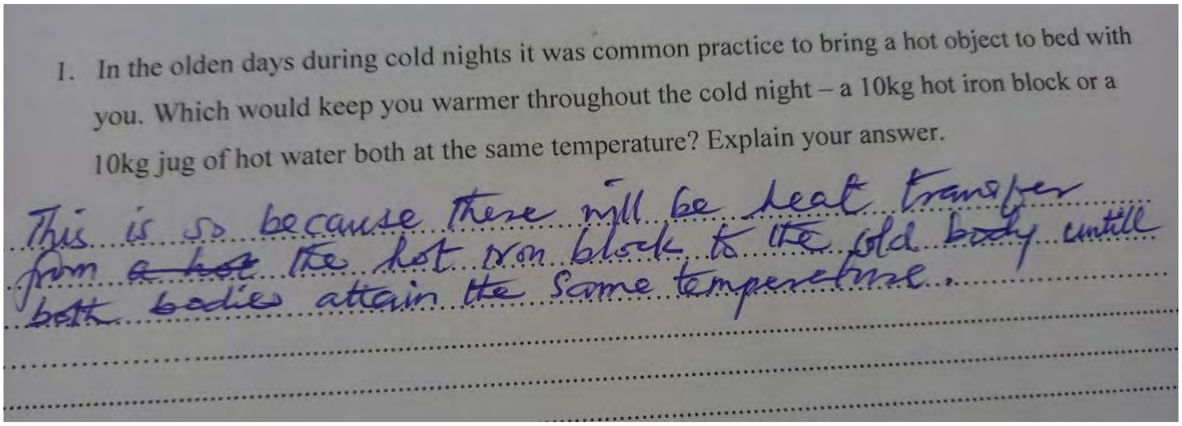
A 10kg hot iron block. This due to the molecules of iron having a high thermal expansi-on. Also, the molecules of solid are closely packed as compared to water molecules

Example 6: Students' sample response two to sample question three


1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

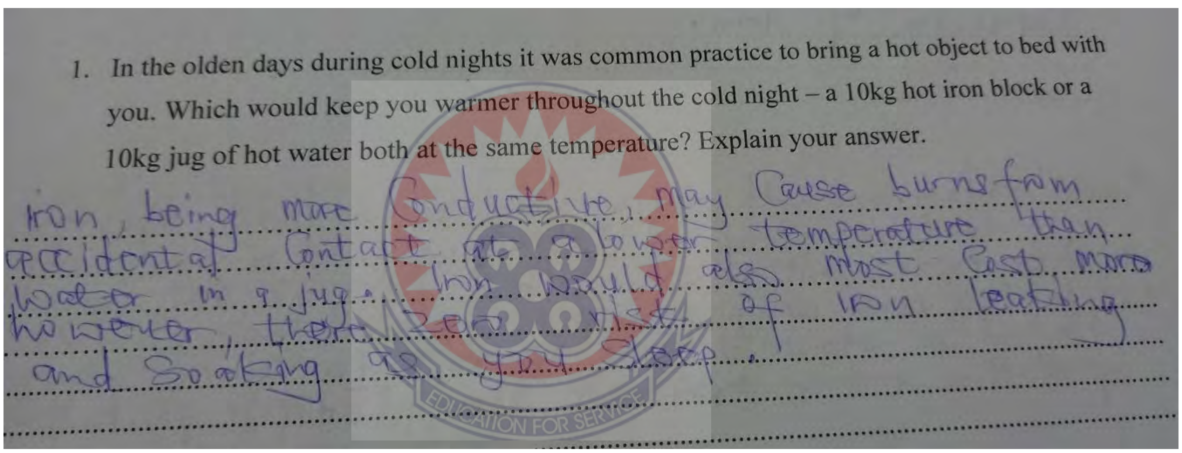
Irons Conductivity also means it would release it's heat faster which could be good if you're mostly trying to get the bed nice and warm quickly, or bad if you're looking for a slow, gradual, release of heat to help keep you warm unit morning.

Example 7: Students' sample response three to sample question three


1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

This is so because there will be heat transfer from ~~a hot~~ the hot iron block to the cold body untill both bodies attain the same temperature.

Example 8: Students' sample response four to sample question three


1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

iron, being more Conductive, may Cause burns from accidental Contact at a lower temperature than water in a jug. Iron would also most Cost more however, there are risks of iron leaking and soaking as you sleep.

Example 9: Students' sample response five to sample question three

A careful examination of all the responses exhibited in Examples 5 to 9 revealed how the pre-service teachers responded to the questions using only everyday practical language instead of formal or expert-like language incorporating the right scientific words. Many of the responses did not express any scientific ideas and lacked the formal nature in which scientific concepts are to be explained. In Pre-test 3, the scientific concept being examined was Specific Heat Capacity of materials and its application to our everyday life. However, none of the exhibited answers provided by the teachers reflected the ideas of the scientific concept. Majority of the explanations were descriptive and everyday in nature, using only ordinary, suggestive and context-specific language that appeared to describe the phenomenon.

The trend observed in the three (3) Pre-tests discussed above was observed in the other two (2) Pre-tests not mentioned in the discourse. Thus, these discussions pertained to all five (5) Pre-tests of the study. A striking feature that was observed in all the pre-tests was that the proportion of participants that provided formal explanations remained consistently low throughout all the Pre-tests. Perhaps, this could be due to the fact that everyday explanations are often rooted in informal language and contexts that individuals encounter in their daily lives. Participants might have been more comfortable and familiar with using everyday language to explain scientific phenomena, as it reflects their personal experiences and observations.

Hence, this study concluded that prior to the use of the POE model-based teaching strategy; the pre-service science students' explanations to concepts were mainly descriptive and everyday in nature, expressed using situational, common-context and informal practical language. This could be explained by the fact that although the concepts on Heat and Thermodynamics were quite familiar to them, because they might have encountered them in their pre-tertiary studies, they could have been engaged in the teaching and learning of these concepts through other teaching strategies other than the POE model-based teaching and learning strategy. These findings were congruent with those by Ohlemeier et al., 2012, as well as Davis and Anyan (2021) who found in their studies that the common approach to teaching at the various second cycle institutions in Ghana emphasised memorisation of scientific facts and the replication of scientific experiments. These tend to stifle students' abilities to provide scientific explanations using formal language or terminologies as expected. Thus, instead of using the knowledge gained from the textbook to explain the concepts, which could have enabled them to acquie and use formal texts, the students fell on the use of their own everyday experiences associated with the concepts. Perhaps, if the students had been engaged in more interactive teaching and learning methods aside the common traditional methods mostly employed at pre-tertiary levels, they would have elaborated more on their use of scientific language. These findings are also be in agreement with a study by Chenoweth (2003) in which the author described the direct mode of teaching and learning as being very rigid and providing little room for adjustment. Chenoweth further stated that such teaching strategies restrict the use of active learning strategies such as workshops, dialogues, and collaborative studies.

Lin (2006) and Garza (2003) also supported the findings of this study by indicating that even though traditional teaching methods such as the lecture teaching method had been touted as beneficial to teaching and learning; because it gave full play to teachers' roles as leaders, and enabled learners to obtain more knowledge, it made learners lose their learning initiative and creativity. This finding also agrees with Reeder's (2022) claim that in lectures, active interaction with learners is limited, with less emphasis on practice, and dwelling on recitation. Perhaps, the students' previous engagements in science teaching and learning tended to be mainly through direct and other traditional teaching methods. These teaching methods seem to have inhibited their abilities to provide explanations to science concepts using the formal language of science.

5.1.2 Discussion of Research Question Two:

What is the nature of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?

Research question two sought to determine the nature of the pre-service teachers' explanations to the concepts on Heat and Thermodynamics, after they had been exposed to the POE model-based interactive teaching and learning. The results of the students' responses to the tests after the intervention, that is, the Post-tests are indicated in Table 9 above.

Data from Table 9, Figure 5 and Figure 6 revealed that overall; majority of the students' responses fell in the categories of formal and causal explanations. These were observed in all five Post-tests of the study. It was observed that majority of the pre-service teachers had transitioned from providing informal to formal explanations of concepts. This suggested that the pre-service teachers became more proficient in providing formal explanations over time, indicating the effectiveness of the POE model-based interactive teaching approach.

Sample responses of students' explanations to a given question in Post-test 5, which was on the concept of Heat transfer (Convection and Radiation) are exhibited below.

Sample Question 4: *A boy says his mother mostly bakes bread on the top shelf inside the oven because it is hotter at the top than at the bottom.*

Student A says that it is hotter at the top because heat rises.

Student B says that it is hotter because metal trays concentrate the heat.

Student C says it is hotter at the top because the hotter the air the less dense it is.

Student D disagrees with them all and says that it is not possible to be hotter at the top.

Which student do you think is right? Give the reasoning for your choice.

Sample response1:

Student C. "This is because when air molecules in the oven gain heat from the bottom, they become less dense and rise to the top shelf. This process continues until all the air molecules gain heat and rise to the top shelf making it more hot than at the bottom".

Sample response 2:

"As they become hot, they become less dense hence rise up for cooler air which is denser occupy the down".

Sample response 3:

"Student C is right. This is because when heat becomes less dense it moves to the top and replaces the more dense air at the upper part of the top shelf. Hence baking at the top shelf of the oven will be more suitable".

Sample Response 4:

C "the boy is right because the hot air inside moves to the top and relatively cooler air goes down the oven making the topmost part of the oven to be hotter than downward compartment. This makes the bread at the top bake faster than the one at the bottom".

The sampled responses revealed the students' answers were mainly formal and causal in nature, using the correct scientific language, and also being able to give the cause and effect explanations of phenomena. The causal effect of the density of warm and cold air on the set up of convection current in the oven was established by the students' explanations. Many of the responses were able to indicate that warm air is lighter than cold air because its particles have more heat energy, which results in the increase in distances between the molecules. This decreases the density, and hence makes it lighter than cold air, and will rise to the top in the oven.

All responses were categorised into causal explanations 26 (35.6%) and formal explanations 47 (64.4%). None of the responses were categorised as everyday nor descriptive; an indication of how the intervention had impacted the nature of the students' explanations.

Post-test 4, tested the nature of the students' responses to questions on the concept of Heat transfer (Conduction). Sample question 5 is an example of a question posed during the test.

Sample Question 5: *A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:*

Student A: They are colder because metal is naturally colder than plastic.

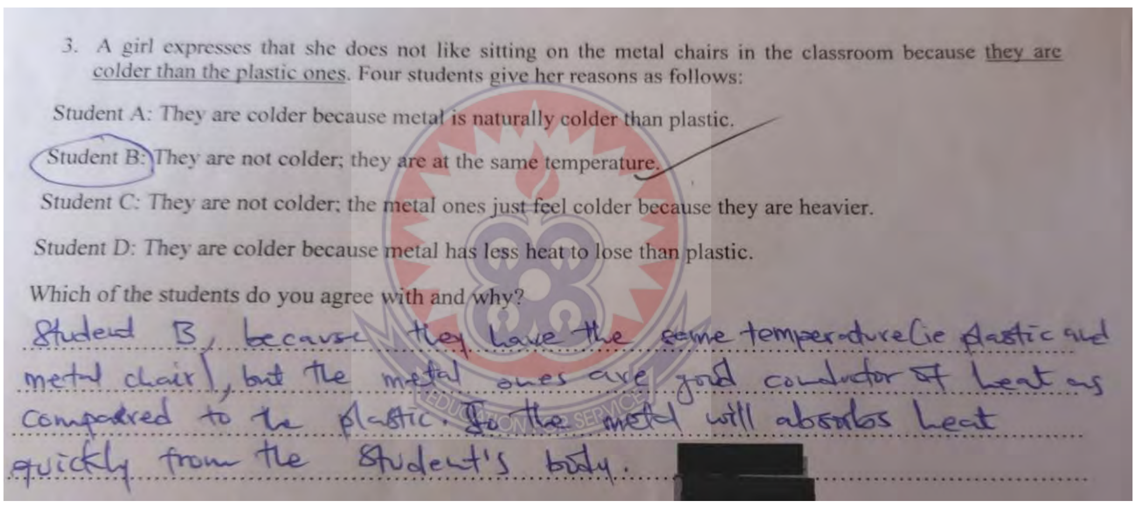
Student B: They are not colder; they are at the same temperature.

Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which student do you agree with and why?

Excerpts of students' responses to sample question 5 are exhibited in examples 10 to 13.



3. A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

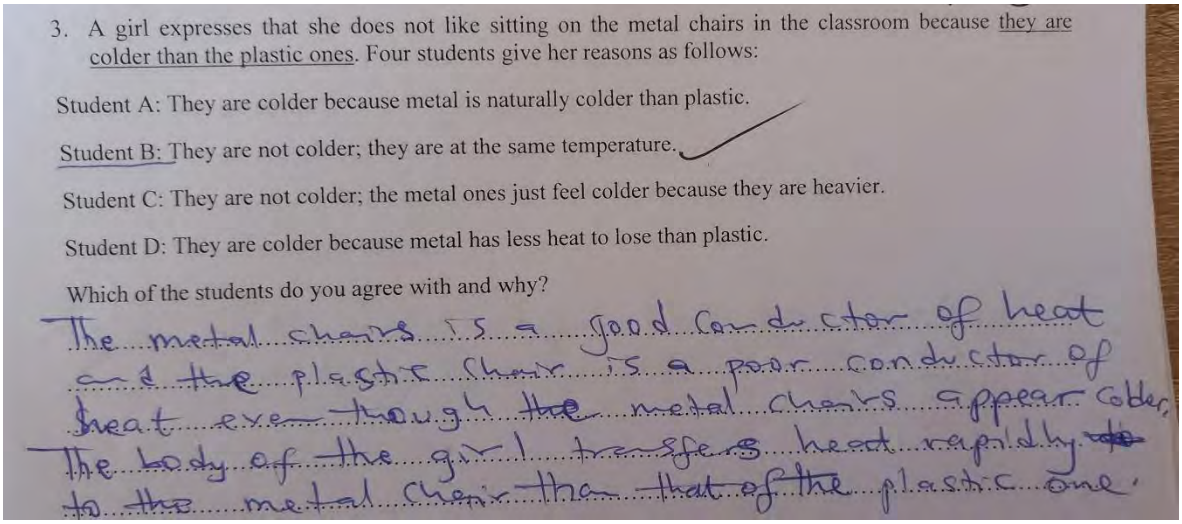
Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which of the students do you agree with and why?

Student B, because they have the same temperature (ie plastic and metal chair), but the metal ones are good conductor of heat as compared to the plastic. So the metal will absorbs heat quickly from the student's body. [redacted]

Example 10: Students' sample response one to sample question five



3. A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

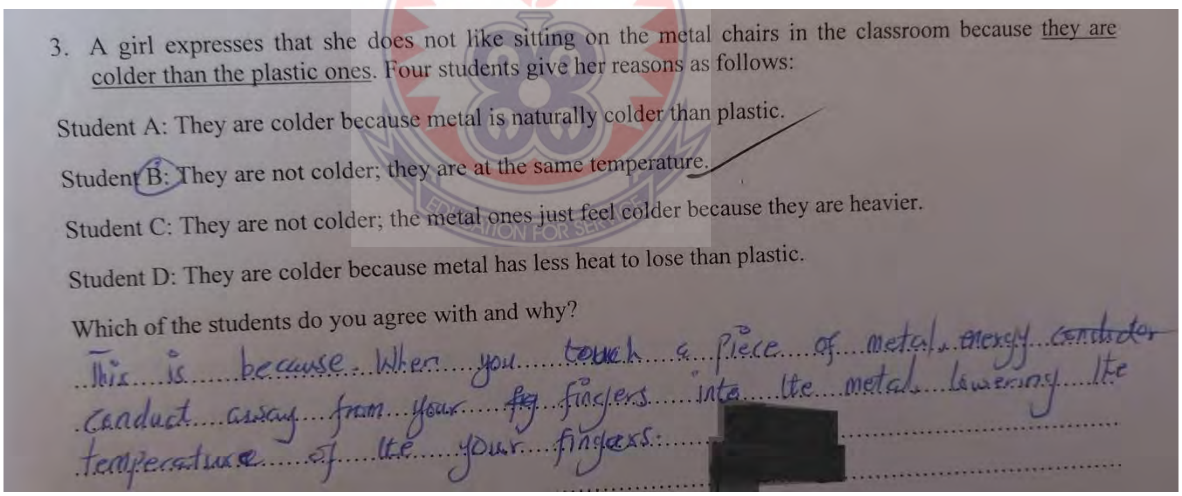
Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which of the students do you agree with and why?

The metal chairs is a good conductor of heat and the plastic chair is a poor conductor of heat even though the metal chairs appear colder, The body of the girl transfers heat rapidly to the metal chair than that of the plastic one.

Example 11: Students' sample response two to sample question five



3. A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

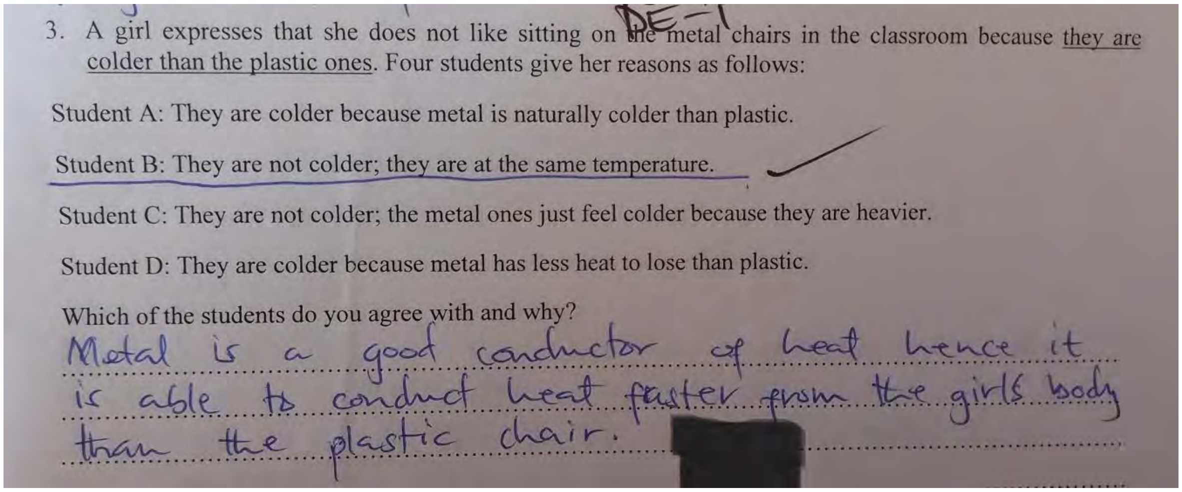
Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which of the students do you agree with and why?

This is because when you touch a piece of metal, energy conductor conduct away from your fg fingers into the metal lowering the temperature of the your fingers. [redacted]

Example 12: Students' sample response three to sample question five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3. A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which of the students do you agree with and why?

Metal is a good conductor of heat hence it is able to conduct heat faster from the girls body than the plastic chair. [redacted]

Example 13: Students' sample response four to sample question five

The sample responses from Examples 10 to 13 of sample question 5 of Post-test 4 revealed students' improvement in their responses to questions. The nature of the responses were observed to be formal using correct scientific terms and phrases. Majority (94.5%) of the responses examined indicated that the students used formal language in explaining the concept of heat transfer (conduction). Hence, they were able to determine that both the metal and plastic chairs were at the same temperature of the room, but the metal felt colder due to the conducting ability of the metal to conduct heat away from the body faster than the plastic. Although some responses were categorised as descriptive explanations (5.5%), no everyday explanation was recorded.

In Post-test 3, the students were tested on the concept of specific heat capacity. This was to determine how the POE model-based teaching and learning strategy affected the nature of their explanations to the concept. Sample question 6 below is an example of a question from Post-test 3.

Sample Question 6: *When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?*

A. Metal pan

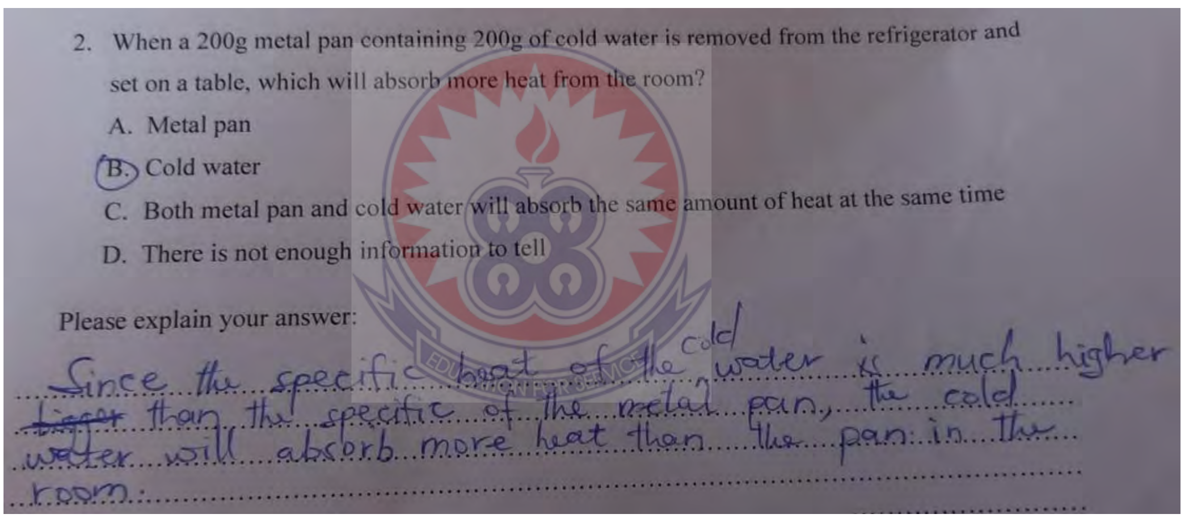
B. Cold water

C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

Excerpts of students' responses to sample question 6 are presented in Examples 14 to 18 exhibited below.



2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

A. Metal pan

(B.) Cold water

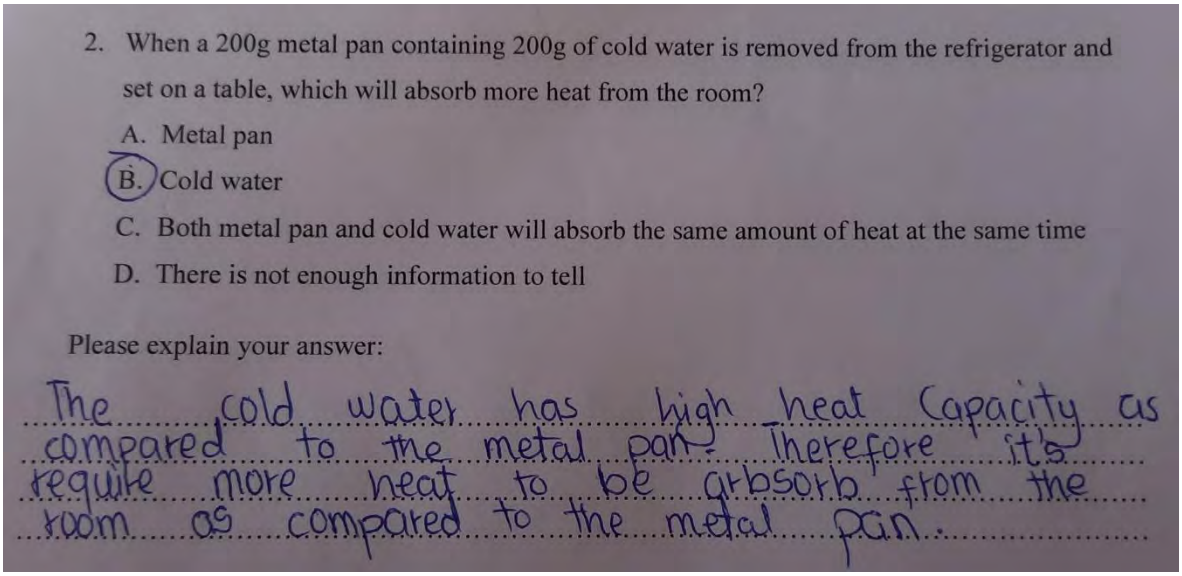
C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

Since the specific heat of the cold water is much higher ~~bigger~~ than the specific of the metal pan, the cold water will absorb more heat than the pan in the room.

Example 14: Students' sample response one to sample question six



2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

A. Metal pan

B. Cold water

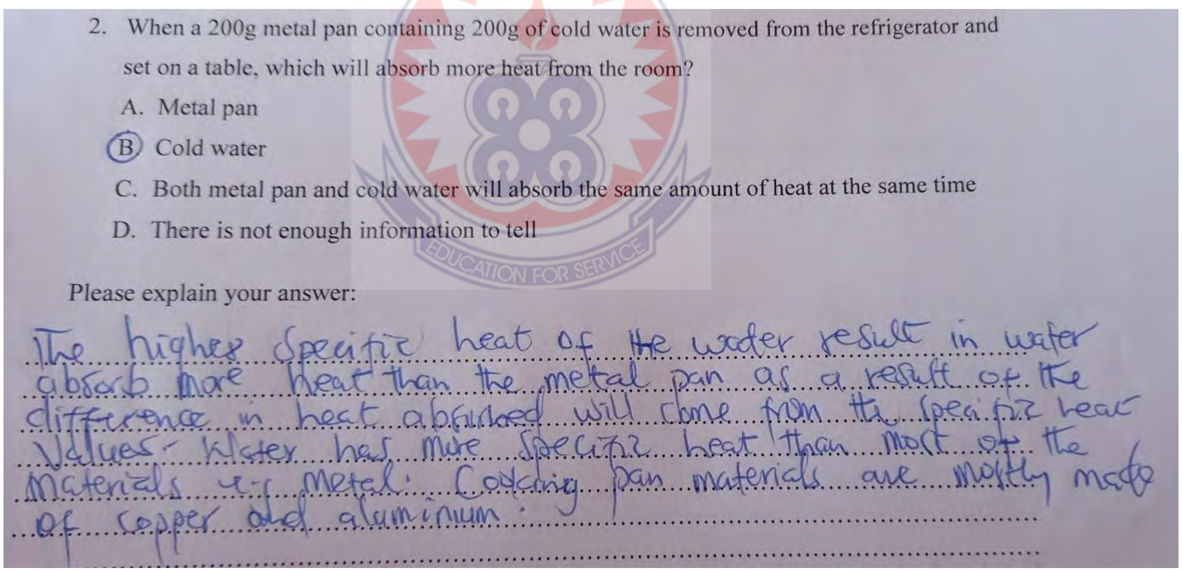
C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

The cold water has high heat capacity as compared to the metal pan. Therefore it's require more heat to be arbsorb from the room as compared to the metal pan.

Example 15: Students' sample response two to sample question six



2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

A. Metal pan

B. Cold water

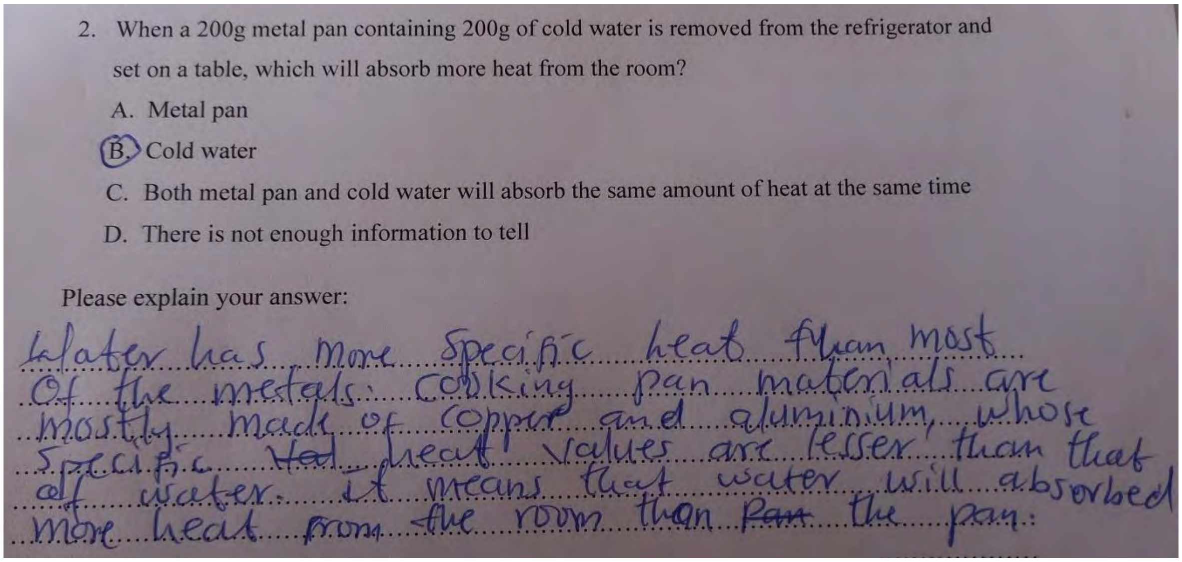
C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

The higher specific heat of the water result in water absorb more heat than the metal pan as a result of the difference in heat absorbed will come from the specific heat values. Water has more specific heat than most of the materials e.g metal. Cooking pan materials are mostly made of copper and aluminium.

Example 16: Students' sample response three to sample question six



2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

A. Metal pan

B. Cold water

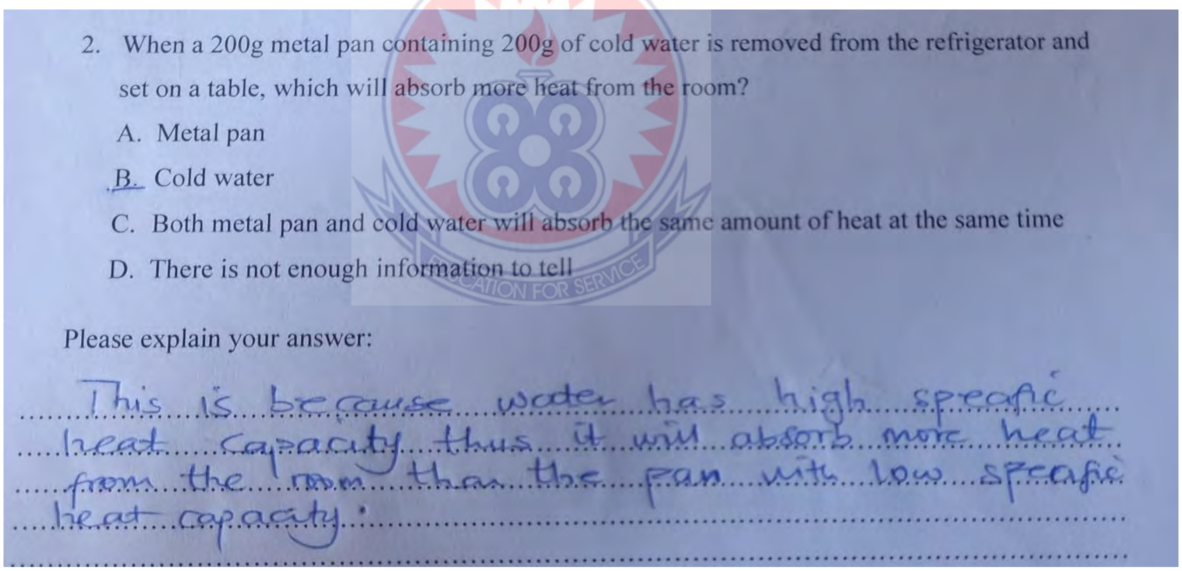
C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

Water has more Specific heat than most of the metals. Cooking pan materials are mostly made of copper and aluminium, whose Specific ~~Hed~~ heat values are lesser than that of water. it means that water will absorbed more heat from the room than ~~Pan~~ the pan.

Example 17: Students' sample response four to sample question six



2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

A. Metal pan

B. Cold water

C. Both metal pan and cold water will absorb the same amount of heat at the same time

D. There is not enough information to tell

Please explain your answer:

This is because water has high specific heat capacity thus it will absorb more heat from the room than the pan with low specific heat capacity.

Example 18: Students' sample response five to sample question six

The sample responses above indicate how the students used the right scientific language of science to describe the given phenomenon in the question. Hence, they were able to explain that the specific heat of the water (liquid or even frozen) is greater than the specific heat of about any common metal, and so then the water will absorb more heat than the pan. The students did not just use informal everyday practical language to describe the process, but rather, used the right expert-like language of science in providing the explanations to the concept under study. This test recorded no (0%) response in the everyday category and only 3 (4.1%) responses were categorised as descriptive. The rest of the responses were formal in nature (49.3%) as well as causal (46.6%).

A careful examination of the students' responses to all the Post-test questions revealed that they were in sharp contrast to most of the responses they gave for the Pre-test questions. This is an indication that the pre-service teachers had made an improved transition from giving mainly informal (everyday explanations which lacked the correct scientific language used in explaining concepts) to formal explanations. This suggests that the use of the POE model-based teaching strategy gave the teachers opportunities to elaborate and expand on their conceptual understanding of the science concepts; and thus, were able to extend their explanations from simple everyday to detailed formal ones.

Thus, this study could conclude that the use of the POE model-based strategy afforded the pre-service teachers the opportunity to observe phenomena, interact with peers to arrive at conclusions and helped eliminate wrong conceptions on the concepts studied. The study observed that even though the students were expected to answer the Pre-tests based on their knowledge gained from the pre-reading assignments in the textbook, majority approached the questions based on their own ideas about these concepts, and so used everyday practical situations to explain the concepts. However, after the intervention, due to the interactive nature of the lessons, majority acquired the formal scientific language needed to provide the explanations to the concepts. This is in agreement with the study by Zacharias (2005), in which the author concluded that using interactive strategies along with the application of the POE model had a positive impact on the nature of science teachers' explanations to concepts. That is, the strategies elaborated the teachers' explanations, and reflected cause-effect reasoning and formal reasoning. The study agreed with research by Kearney and Treagust (2001), White and Gunstone (1992) and Tokur (2011) who all found the POE as a helpful strategy used to promote student discussions in the learning process, thereby increasing their conceptual understanding and reduce their wrong use of terminologies. Moreover, other studies reported that every stage of the POE strategy provided a rich discussion or learning environment for students, hence giving them an advantage in exploring concepts and generating or probing ideas (Phanphech & Tanitteerapan, 2017; Rini et al., 2019; Erdem et al., 2022). Further, engagements in the interactive POE model-based processess enabled the pre-service science teachers to express their understanding by explanations which were written down in the tests. These increased probing among the students and encouraged them to express themselves freely as found by (Dial et al., 2009); by extension, justifying and articulating ideas to increase the acquisition of formal reasoning and use of formal language in science.

Again, the findings of the present study also tends to agree with that of Karamustafaolu and Mamlok-Naaman (2015), who opined that the Predict-Observe-Explain technique improved students' understanding of science topics substantially more than the lecture method. Thus, when the POE model-based teaching strategy was employed in this study, majority of the pre-service science teachers were able to go beyond using situational meanings based on descriptive everyday reasoning to generating well-articulated, formal, conceptual explanations of the phenomena being investigated. Students had to convince each other in their groups before presenting ideas to the whole class.

5.1.3 Discussion of Research Question Three:

What is the quality of the scientific explanations of concepts in science by pre-service teachers before the use of the POE model-based interactive teaching?

This research question sought to determine the quality of students' explanations to concepts before the intervention with the help of Pre-tests. Thus, the depth of scientific reasoning and/or scientific accuracy of the explanations the pre-service science teachers' gave to concepts in Heat and Thermodynamics prior to the use of the POE model-based teaching strategy. In this study, the degree to which the teachers were able to provide complete and well thought-out explanations, using scientifically valid ideas and theories to describe scientific phenomenon being studied corresponded to quality of an explanation.

Table 10, Figure 7 and Figure 8 revealed that the quality of the students' responses to questions in the Pre-tests were mainly partial and wrong, with an average of about 51.7% of all responses falling in the partial explanation category, and 31.5% being wrong explanations. Sound explanations were found to be the least among the categories averaging just about 16.7% overall. Majority of the students' explanations to the concepts under study that were categorised as partial explanations either lacked in-depth scientific knowledge of the phenomena, whereby ideas were incoherent or were scientifically inaccurate, and vice versa; depicting that some level of understanding was evident but not entirely. Those responses that fell under wrong explanations were characterised by confused, contradictory and inaccurate explanations exhibiting minimal understanding of the concepts. This was exhibited throughout the five Pre-tests of the study. However, particularly revealing were the following sample responses of students to some given questions, indicated below.

***Sample Question** 7: Why is it important that a key and its lock should be made of the same or similar materials?*

***Sample response 1 to sample question** 7: "locks are on metal process, so a hard metal key in a softer metal lock will wear the livers or pins until the levers or pin fails and seize, typically in the locked position".*

***Sample response 2 to sample question** 7: "the lock and key must be of the same material because if two different materials are used eg. The lock has been a stronger material than the key will worn off when opening the lock. A hard metal wears a weaker metal so the key and the lock must be of the same metal to prevent wearing off".*

These two sample responses to the given sample question portray how the students lacked conceptual understanding of thermal expansion of materials. Their explanations lacked the correct scientific knowledge, and were portraying confused and incoherent understanding of the scientific phenomena.

Another example is given below.

***Sample Question 8**: Briefly explain which has a greater amount of internal energy – an iceberg or a cup of hot water?*

***Sample response 1 to sample question 8:** "a cup of hot water has a greater amount of internal energy. This is because in the hot cup of water, the movement of molecules will be* *quite faster as compared to the movement of molecules in an iceberg. And internal energy is highly affected by the temperature of the object".*

Sample response 2 to sample question 8: *"hot water will have the greater amount of internal energy compared to that of the ice-berg because the hot water has more kinetic energy and the molecules will move in the hot water but the ice-berg will have no kinetic energy".*

The sample responses to sample question 8 revealed the students' misconceptions about internal energy (the total energy of the motion of the molecules) of substances. They could not determine the difference between temperature and internal energy and gave wrong, inaccurate scientific explanations to the phenomena.

The sample responses above, which were mainly wrong or partial explanations, and were in the majority, revealed that the pre-service teachers did not have in-depth understanding of the scientific concepts. This was portrayed in the "shallowness" of their scientific reasoning, giving explanations that were mere description of objects and relationships among concepts; which were inaccurate as well. From the reviewed literature (Treagust & Harrison 2000), a scientific explanation must be applicable to a phenomenon and accurate in the context of those phenomena; that is, the explanandum should be a logical consequence of the explanans. However, this was not the case in about 83% of the explanations provided by the pre-service science teachers. Hence, the study concludes that the quality of the students' explanations to concepts prior to the use of the POE model-based teaching and learning strategy as an intervention were mainly partial and wrong; lacking sound scientific knowledge and deep reasoning, largely characterised by scientifically inaccurate ideas, exhibiting contradictory and incoherent characteristics and portraying minimal understanding of concepts. The pre-service teachers provided scientifically inaccurate, partial and/or wrong explanations to the scientific concepts in Heat and Thermodynamics.

These findings could be as a result of two factors: first, their lack of conceptual understanding leading to their inability to acquire the correct scientific knowledge needed to express relationships among phenomena; and secondly, the misconceptions students had about the concepts of Heat and Thermodynamics from their pre-tertiary studies. Undoubtedly, these students had had previous encounters in their science studies about the concepts of Heat and Thermodynamics relying on textbooks, chalk and talk only, limiting their conceptual understanding of these concepts. As found by Darling-Hammonda et al. (2020), a call to construct a scientific explanation is a call to exhibit the ability to provide both appropriate explanation and the evidence of conceptual understanding. Hence the pre-service teachers not being able to provide accurate explanations to concepts implied they lacked conceptual understanding, and as such lacked the requisite scientific knowledge. Many studies have proven that the ability of students to provide explanations to concepts is linked to conceptual understanding, and is a way to show understanding (Southerland et al., 2001; Zuzovsky & Tamir 1999).

The findings were also emphasised by Nalkiran and Karamustafaoglu (2020) in which they indicated that many students have many misconceptions about many science concepts, did not have any scientific knowledge about the relationships among the science concepts, and portrayed relationships that were far from scientific.

5.1.4 Discussion of Research Question Four:

What is the quality of the scientific explanations of concepts in science by pre-service teachers after the use of the POE model-based interactive teaching?

The quality of the students' explanations to concepts after the intervention of the POE teaching strategy was assessed to determine if there was any change in their level of scientific reasoning, knowledge and accuracy, with the help of the Post-tests. The results of the Post-test assessment presented in Table 11, shows the distribution of the quality of students' explanations among the categories wrong, partial or sound explanations.

The results revealed that on the average, majority (89.6%) of the students' responses were categorised as sound explanations for all the five Post-tests; and only a few explanations were categorised into partial (8.5%) and wrong (1.9%). Thus, the use of POE model-based teaching strategy appeared to have promoted in-depth scientific reasoning in the pre-service teachers, leading to enhanced scientific knowledge and conceptual understanding. The strategy could also have contributed to the improvement in the teachers' ability to generate scientifically accurate explanations of scientific phenomena.

Following are excerpts of some responses from the pre-service teachers to some given questions depicting the deep scientific reasoning behind the explanations to the concepts, indicating soundness in the explanations are exhibited in the examples below.

In Post-test 2, a question on thermal expansion of materials was asked; expressed in ample Question 9 below.

***Sample Question 9**: When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?*

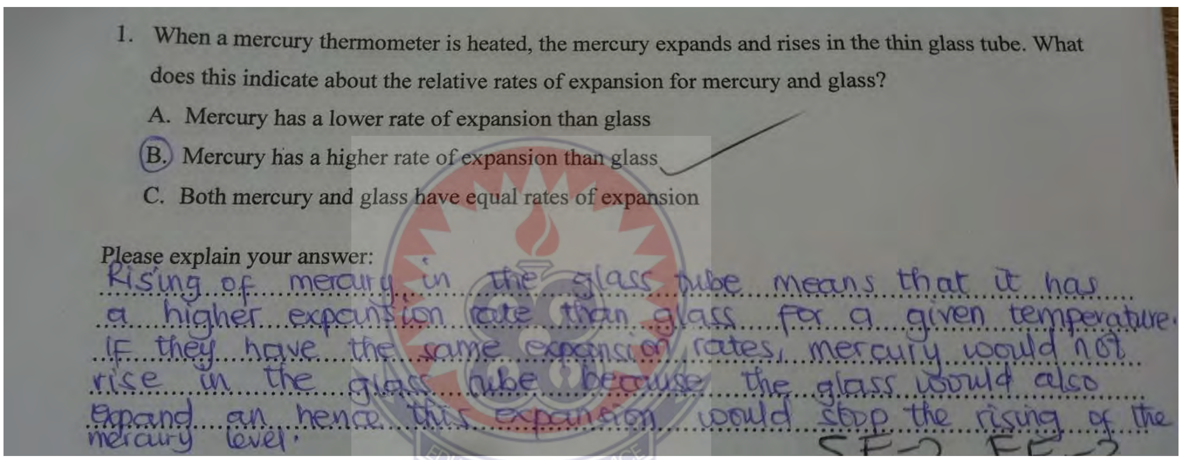
A. Mercury has a lower rate of expansion than glass

B. Mercury has a higher rate of expansion than glass

C. Both mercury and glass have equal rates of expansion

Please explain your answer:

Examples 19 to 22 are excerpts of some responses to the sample question by the students.


1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?

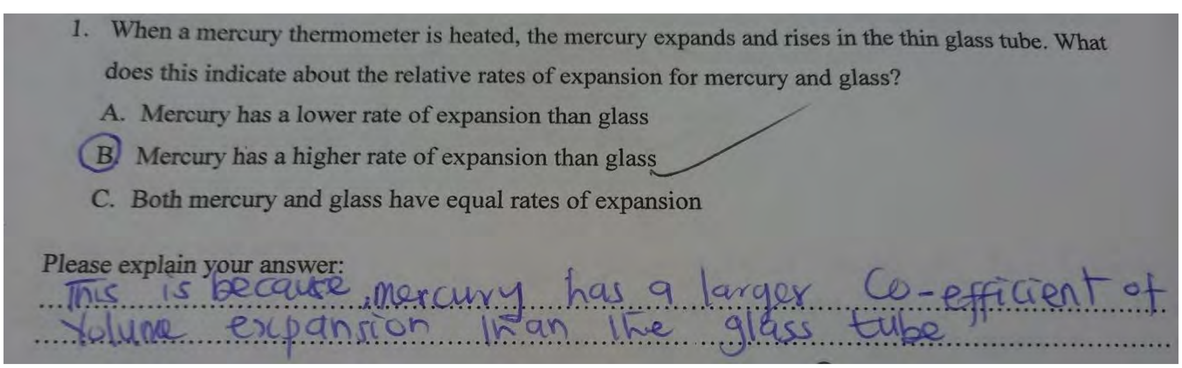
A. Mercury has a lower rate of expansion than glass

(B.) Mercury has a higher rate of expansion than glass

C. Both mercury and glass have equal rates of expansion

Please explain your answer:
Rising of mercury in the glass tube means that it has a higher expansion rate than glass for a given temperature. If they have the same expansion rates, mercury would not rise in the glass tube because the glass would also expand an hence this expansion would stop the rising of the mercury level.

Example 19: Students' sample response one to sample question nine


1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?

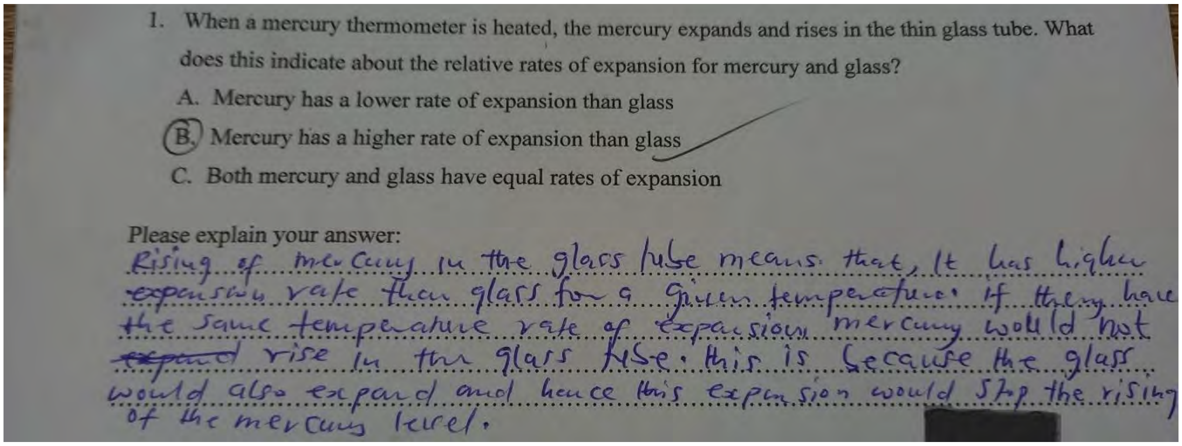
A. Mercury has a lower rate of expansion than glass

(B) Mercury has a higher rate of expansion than glass

C. Both mercury and glass have equal rates of expansion

Please explain your answer:
This is because mercury has a larger Co-efficient of Volume expansion than the glass tube

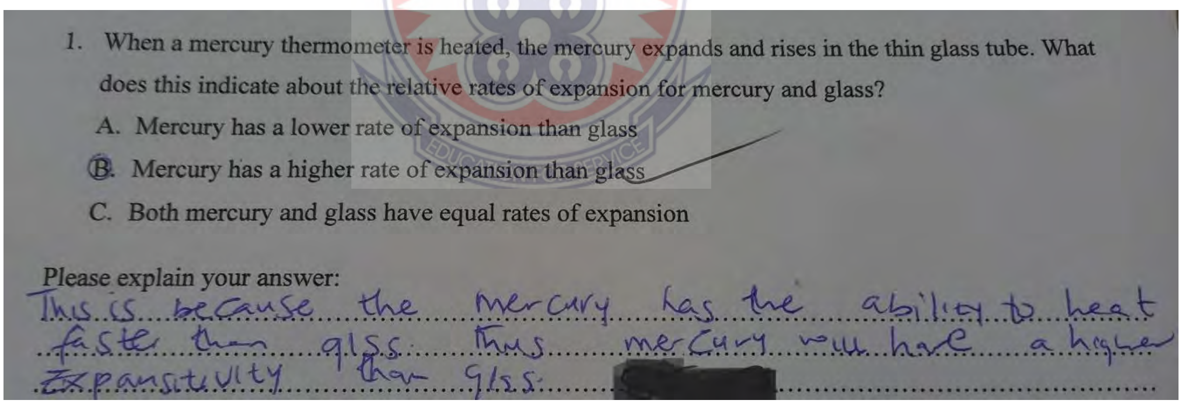
Example 20: Students' sample response two to sample question nine



1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?
   A. Mercury has a lower rate of expansion than glass
   (B.) Mercury has a higher rate of expansion than glass
   C. Both mercury and glass have equal rates of expansion

Please explain your answer:
Rising of mercury in the glass tube means that, it has higher ~~expansion~~ expansion rate than glass for a given temperature. If they have the same temperature rate of expansion mercury would not ~~expand~~ rise in the glass tuse. this is because the glass would also expand and hence this expansion would stop the rising of the mercury level. [redacted]

Example 21: Students' sample response three to sample question nine



1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?
   A. Mercury has a lower rate of expansion than glass
   (B.) Mercury has a higher rate of expansion than glass
   C. Both mercury and glass have equal rates of expansion

Please explain your answer:
This is because the mercury has the ability to heat faster than glss. Thus mercury will have a higher Expansivity than glss. [redacted]

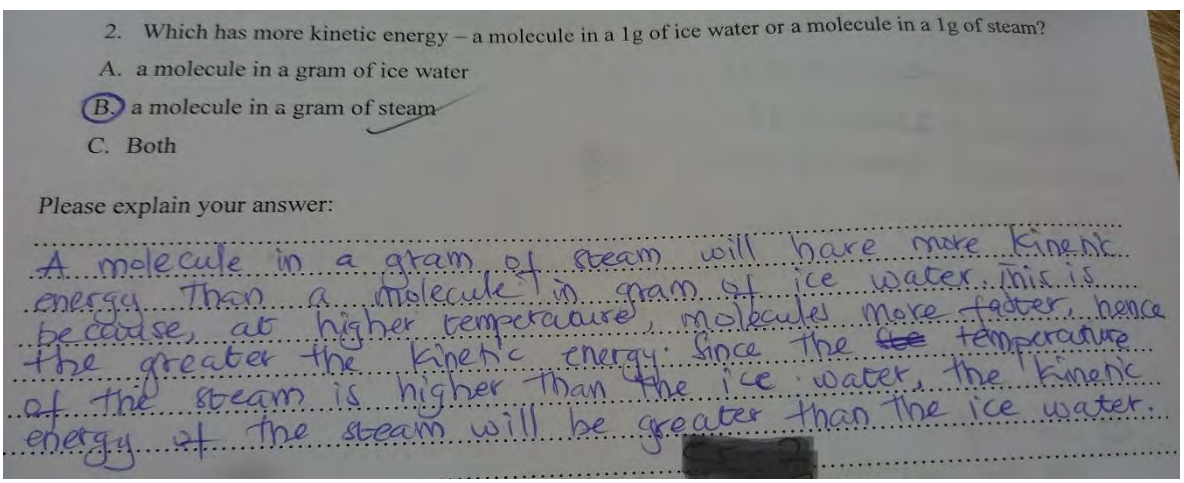
Example 22: Students' sample response four to sample question nine

From the sample responses displayed in Examples 19 to 22, it was evident that the pre-service teachers were able to give scientifically accurate and in-depth explanations regarding the concept of thermal expansion; depicting a good knowledge of the scientific processes involved in the phenomena. The pre-service teachers depicted in-depth scientific knowledge by explaining that the relative rates of expansion for mercury and glass are different. Again, they were able to reason deeply that the different rates of expansion were due to each substance having a different coefficient of expansivity for a given change in temperature. Thus, showing that mercury rising in the glass tube indicates that it has a higher rate of expansion than glass for the same temperature change.

Some responses to Sample question 10 on concepts of heat and temperature from Post-test 1, displayed in Examples 23 to 25 further reiterated the pre-service teachers' advancement in their reasoning depths, scientific accuracy and scientific knowledge of concepts.

Sample Question 10: *Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?*
A. a molecule in a gram of ice water
B. a molecule in a gram of steam
C. Both
Please explain your answer:

The sample responses are displayed below.

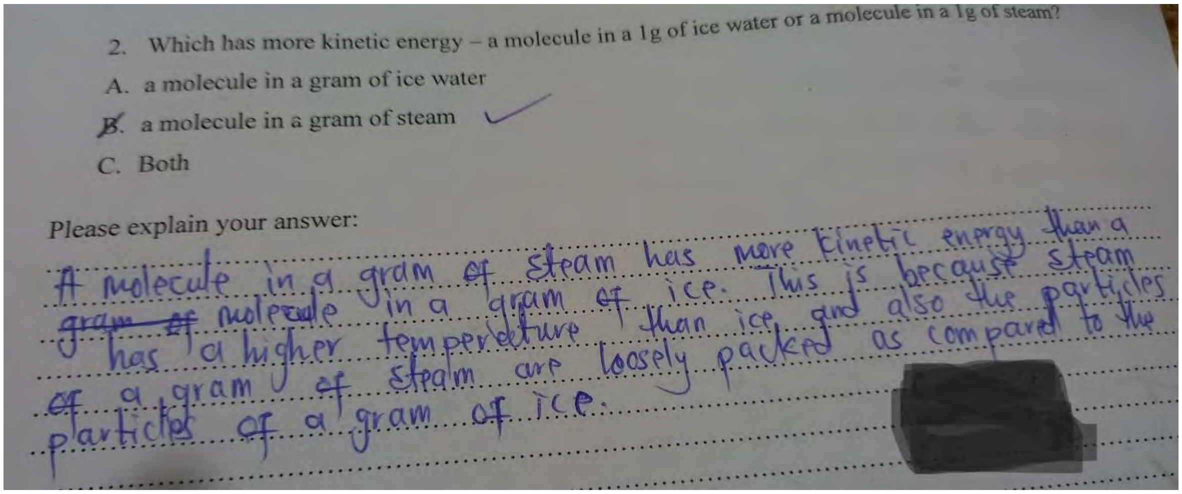

2. Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?
A. a molecule in a gram of ice water
B. a molecule in a gram of steam
C. Both

Please explain your answer:

A molecule in a gram of steam will have more kinetic energy than a molecule in gram of ice water. This is because, at higher temperature, molecules move faster, hence the greater the kinetic energy. Since the ~~the~~ temperature of the steam is higher than the ice water, the kinetic energy of the steam will be greater than the ice water.

[redacted]

Example 23: Students' sample response one to sample question ten



2. Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?

A. a molecule in a gram of ice water

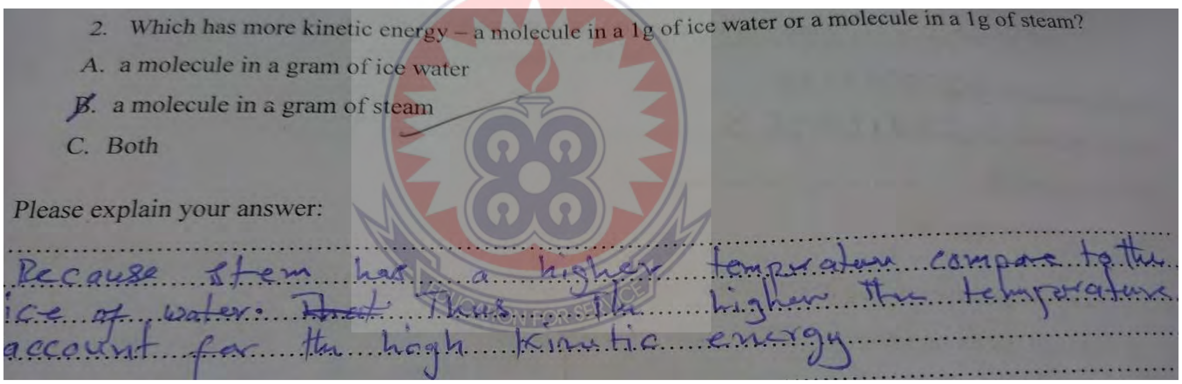
B. a molecule in a gram of steam ✓

C. Both

Please explain your answer:

A molecule in a gram of steam has more kinetic energy than a ~~gram of~~ molecule in a gram of ice. This is because steam has a higher temperature than ice and also the particles of a gram of steam are loosely packed as compared to the particles of a gram of ice. [redacted]

Example 24: Students' sample response two to sample question ten



2. Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?

A. a molecule in a gram of ice water

B. a molecule in a gram of steam

C. Both

Please explain your answer:

Because stem has a higher temprature compare to the ice of water. ~~That~~ Thus the higher the temperature account for the high kinetic energy

Example 25: Students' sample response three to sample question ten

In the above sample responses, the students exhibited conceptual understanding of the phenomena of heat and temperature, and thus, were able to explain accurately that if a body has a high temperature, each of its molecules has, on the average, a large amount of kinetic energy; hence 1g of steam would have more kinetic energy than 1g of ice water. The students made a steady progress in their level of reasoning from the post-intervention of the POE model-based teaching strategy, and seemed to have advanced in their ability to provide quality explanations to the concepts.

Comparing these sample responses (Examples 23-25) to the explanations given by the students during the Pre-tests, it is quite evident that their depths of scientific reasoning had deepened, and they had made great improvements in the level of scientific accuracy of their responses. Hence, the quality of the pre-service science teachers' explanations was found to be better. This is similar to what Zacharias (2005) found in a study conducted on how practicing teachers' construction of explanations develops from interactive simulations alongside the POE model. The results of the study indicated that the use of computer simulations along with the application of the POE model had a positive impact on the nature and quality of the science teachers' explanations. The study further revealed that the science teachers had improved in their ability to generate scientifically accurate explanations and fostered in-depth advancement in their provision of explanations to concepts under investigation.

These findings are consistent with those of prior studies, which have concluded that implementing the POE model-based teaching technique is a useful method for enhancing science teachers' conceptual understanding of their subject matter. Further, these studies have revealed that pre-service teachers who have been taught scientific concepts using the POE model have shown improvements in their understanding of scientific concepts, and provided more accurate and detailed explanations compared to pre-service teachers who did not use the POE model (Tao & Gunstone, 1999; Zacharia & Anderson, 2003). Therefore, these findings of the studies suggest that using the POE model-based teaching strategy can be a very useful teaching approach for pre-service teachers. This is because it can help them to better understand the scientific concepts and improve the quality of their scientific explanations. Consequently, the POE approach promotes student-centered learning by encouraging pre-service teachers to actively interact with scientific ideas and make predictions about the results, which can lead to a better knowledge and increased ability to explain the concepts. This is in congruent to the constructivist theory that the study hinged on, and which emphasises on learner centeredness.

The findings of the present study also tend to agree with a similar study by Nalkiran and Karamustafaoglu (2020), in which the authors concluded that applying the POE model together with Pre-test-Post-test design largely eliminated students' misconceptions and replaced them with scientifically-correct concepts and relationships. Thus, using the POE approach in conceptual teaching across a variety of classes, courses, and topics is strongly recommended.

5.1.5 Discussion of Research Question Five:

How do pre-service teachers perceive the use of the POE model-based interactive teaching of concepts in science?

After the implementation of the POE model-based strategy, the students' opinions of the teaching strategy was assessed to determine how they perceived the strategy. To help analyse these perceptions, the students' responses to the closed-ended items of the questionnaire were categorised into three perception themes for analysis. These themes included ***Cognitive perceptions*** (students' perceptions of the use of the POE strategy on their conceptual learning of the science concepts), ***Behavioural perceptions*** (students' perceptions of the use of the POE strategy on their attitudes towards science) and ***Emotional perceptions*** (students' perceptions of the use of the POE strategy on their interests and motivations in their study of the science concepts). A thematic analysis and discussion of the perceptions of the students on the use of the POE model-based strategy was carried out, and is presented below.

- ***Cognitive perceptions of the POE Model-based Strategy***

Data from Table 12 and the graph in Figure 11 indicate that overall, the students' perceptions of the use of the POE model-based strategy on their conceptual understanding of the science concepts were positive. This is due to the fact that majority of the students' responses to the categorised items were in the ranges of strongly agree and agree, with only few responding otherwise. Hence, the students had positive cognitive perceptions of the POE model-based teaching and learning strategy.

The students' positive perceptions could be attributed to the fact that the POE model-based teaching and learning strategy is considered a problem-oriented and inquiry-based approach to science teaching and learning. Hence, it encouraged the pre-service science teachers to engage in active learning through questioning, making observations, and explaining ideas. The use of the strategy also seems to have improved their conceptual understanding of the Heat and Thermodynamic concepts, thinking processes, and learning outcomes. These findings tend to agree with the study by Erdem Özcan and Uyanık (2022), in which they opined that the POE is an effective strategy in increasing students' academic achievement. These excerpts of responses that students provided to open-ended items on the questionnaire which related to their cognitive perceptions of the model further emphasises the findings of the study.

Question: Please explain what factors led to your positive perceptions.

"It is positive because it enhances my ability to collect more information about science which help me to organise and test my ideas, solve problems and apply what I have learnt".

"Because science has more to do with daily life activities and that led me to positive perception of science".

"The impact of science in our life. The use of the idea obtained from science to explain numerous things that occur in our daily lives to my positive perception".

"The factors that led to my positive perceptions about science was that I was able to relate the concept of science which was taught in class to everyday life and I was able to get more ideas from my colleagues whenever they answered questions".

"I was having a mindset of the perception that science is very difficult subject but through the POE model-base strategy, I have been able to understand science very well and understand my daily life".

The excerpts above emphasised that after engaging the students using the POE model-based teaching and learning strategy, they developed a deeper understanding of scientific concepts. Thus, through the process of scientific inquiry of the POE, the students were able to construct their own understanding of scientific phenomena, rather than simply memorising information. This conceptual understanding of concepts was reflected in their ability to apply scientific concepts in new contexts, explain scientific phenomena using their own words and relate concepts to everyday phenomena.

The above findings are in agreement with that of the study by Jasdilla, Fitria and Sopandi (2019), which revealed that through the POE strategy, students' mental models developed and became well-formed due to the experiences they gained in learning, and which were not based on rote memorisation. The authors further revealed that, through the POE strategy, students were trained to create hypotheses (conjectures) on a phenomenon.

It was also inferred from the students' responses was that they had developed critical thinking skills. This might have been achieved through the processes of posing questions to each other during their interactions, observing and explaining phenomena through the interactive lessons and discussions, and analysing ideas obtained before presenting them. Hence, they were engaged in higher-order thinking processes, leading to an increased ability to identify and evaluate evidence, to make connections between different scientific concepts, and to solve problems. Additionally, the students' cognitive perceptions were influenced by their ability to apply their knowledge to real-world situations. By engaging in authentic problem-solving tasks, the pre-service science teachers developed a better understanding of the relevance of scientific concepts to their own lives and to society as a whole.

The following excerpts of students' responses allude to the above findings. These were responses from the same question stated previously.

Question: Please explain what factors led to your positive perceptions.

"It makes me confirm my predictions, with evidence and facilitates understanding".

"I never understood some concepts in science which made me feel that science is just something people have just developed with no proof but upon the POE, I've got to know that science is just a daily activity which we do in our daily life and has made me to have positive perception about science. Especially, I dint understand why AC were placed at the top corner of our rooms".

"Science enlightens the mind, it gives rom to explore and science made to think critically".

"This course and POE model-based teaching has increased critical thinking among learner and preparedness towards learning".

"POE model-based strategies give advanced understanding about science. Improves creativity and critical thinking. It also provide a problem solving environment".

"Nature influenced my perception about science knowing that different things come together to produce some things we see today or how things do happen, how somethings came about. I was always curious".

In conclusion, the cognitive perceptions of the pre-service science teachers to the POE model-based teaching and learning strategy were positive, as this approach to the teaching and learning of concepts in science emphasises active learning, critical thinking, and real-world application of scientific concepts. The study therefore concludes that engaging students in this approach helped them develop a deeper and more meaningful understanding of scientific concepts and processes, which ultimately, could lead to more successful and fulfilling careers in science and related fields.

- ***Behavioural perceptions of the POE Model-based Strategy***

Data on the students' perceptions of the use of the POE model-based strategy on their attitudes towards science, a characteristic of their behavioural perceptions, from Table 13 and Figure 12, indicated positive perceptions. This is as a result of a majority of responses being skewed towards the scales of Strongly Agree and Agree, a strong indication of positive perceptions. Consequently, the study concluded that the students had positive behavioural perceptions towards the use of the POE model-based strategy on their study of the science concepts.

The study revealed that majority of the students prepared before attending classes, by doing their pre-reading assignments. This was due to the fact that the pre-reading assignments formed the bases of the Pre-tests, and as such doing it could lead to success in the test. Therefore, the attitude of ensuring that one was prepared before attending lectures was enhanced. Again, interactions among the students, and learning from each other became part of their learning routines, leading to positive changes in behaviour among them. Some excerpts of students' responses that revealed the findings above are indicated below.

"POE model-based strategy has exposed me to the new ways of learning science and how to learn and benefit in a group discussion".

"This is because it enhances my preparation and seriousness towards the lecture for the lessons, it also helped me to interact with people in the class and get to learn from them".

"Because it makes me prepare before coming to lectures and also help me understand the subject areas".

"Because I hardly read any reading assignment given but with the POE model, there is awakens within me for reading both before and after lectures. I was able to develop such character for other courses too".

"It prepares me learn from my colleagues and also helped me understand some concepts".

"It makes you an active learner and also gave me the opportunity to learn how to work with my mates".

"This is because it helps me to prepare ahead before coming to class and also learn a lot from my colleagues".

"I was able to relate the concept of science which was taught in class to everyday life and I gained much knowledge from my colleagues".

"It has improved my team work efforts since I contribute more in group meetings".

These findings could be attributed to the social constructivist approach of the POE model-based teaching and learning strategy, which emphasised on active student-student interactions and discussions during the various stages of the study. The model actively engaged students in the processes of scientific inquiry and discovery learning, through a cycle of predicting, observing, and explaining phenomena. This seems to have influenced their attitudes towards learning the science concepts, resulting in a general positive attitude towards the use of the strategy. Just as Erdem, Özcan and Uyanık (2022) asserted in their study, students who were engaged using the POE model had higher levels of behavioural engagement, positive attitudes and critical thinking skills compared to those who were taught using traditional lecture-based methods. The findings also confirm a previous study by Vadapally (2014), which found out that, students who were engaged using the POE model had positive perceptions towards the study of science compared to those who were taught using traditional methods. Furthermore, Vadapally found out that students who were taught using the POE model had more positive attitudes towards science and were more interested in pursuing careers in science. A similar conclusion was opined by Oluwasegun and Owolabi (2021), who also revealed that the POE strategy positively influenced the attitudes of students towards science.

In conclusion, the use of the POE model-based interactive teaching of concepts in science has been found to positively impact pre-service teachers' behavioural perceptions towards the study of science, including their levels of interactions, preparations towards science lessons and ability to apply scientific knowledge to real-world situations. Therefore, science educators should consider using the POE model in their teaching practices to enhance pre-service teachers' behavioural perceptions and ultimately improve science education outcomes.

- ***Emotional Perceptions of the POE Model-based Strategy***

Considering data from Table 14 and Figure 13, the pre-service teachers' perceptions of the use of the POE model-based interactive teaching of concepts in science on their emotional perceptions were generally positive. That is, majority of their responses to the items on the questionnaire pertaining to their interests and motivation towards the study of science were positive; generally agreeing to the positive statements, and disagreeing to the negative statement.

Majority of the respondents were of the view that the POE model-based strategy did not discourage them in their study of the science concepts, made them enthused about studying the concepts, and made their learning of these concepts fun; resulting in a positive influence of their perceptions of the model. Again, a majority did not perceive the use of model in their learning as tedious. The implications of the above are that they positively perceived the use of the POE model-based strategy on their interests in the study of the science concepts.

Excerpts of students' responses that revealed their emotional perceptions of the POE strategy on their study of the science concepts are presented in the following quotes.

"I prefer it because it enhances my interest of learning and preparing before coming to class".

"I initially and still learn science because it is fun, science helps me to broaden my knowledge on the natural world and the unique ways of matter relations. I always have fun when studying and learning as well".

"Because, before the encountering to the POE, I used to come to class empty head without learning anything before coming to class I don't pay much attention in class because there was no post work for me to do after the class".

"The POE is best for teaching and learning. It made the class very interactive and lovely which made the course very easier to learn. I wish teachers use POE mode".

"POE made learning fun also made me prepare before coming to class it has helped me to learn from my mates".

"POE influenced my perception about science in diverse ways. it also made me curious about the study of science. it also made me more engaged with my course mates".

"For introducing us to a strategy as fun as POE. thank you before, there was a rumor that this course is difficult but POE has made it really simple".

These excerpts above reveal how the students perceived the use of the POE on their interests and motivations in studying science. Many were motivated to always prepare before attending classes, had fun during the lessons, became enthused about lessons and improved on their relationships with their colleagues.

These findings tend to agree with previous studies that have shown that pre-service teachers who use the POE model-based interactive teaching of concepts in science have positive emotional perceptions, such as feeling interested, engaged, motivated, and confident (Erdem et al., 2022; Karamustafaoğlu & Mamlok-Naaman, 2015). This suggests that using the POE model-based strategy can create a positive learning environment that promotes student interest and motivation.

Moreover, the use of the POE model in science education is likely to help pre-service teachers to develop their own teaching strategies in science and enhance their confidence in teaching the subject. This, in turn, could positively impact their own teaching practice and ultimately benefit their students, just as other studies considered that the POE technique is useful for helping students learn concepts, build positive attitudes, and boost their interests in scientific courses. These assertions are in congruent with previous studies carried out by different researchers (Demircioğlu et al., 2017; Tokur, 2011; Bilen & Aydoğdu, 2010).

Finally, the POE model-based interactive teaching of concepts in science seems to be an effective teaching approach that not only improves students' understanding of scientific concepts but also positively impacts their behavioural and emotional perceptions towards the study of science. This suggests that science educators should consider using the POE model-based strategy in their teaching to create a more engaging and motivating learning environment for their students.

5.1.6 Discussion of Research Question Six

What is the difference between females and males in their perceptions of the use of the POE model-based interactive teaching of concepts in science?

Naturally, there are differences between females and males biologically, and this could result in differences in their way of learning (conceptual understanding, attitudes and interests) science concepts. This study sought to determine if any gender differences existed among the pre-service science teachers in their perceptions towards the use of the POE model-based teaching strategy in their learning of the concepts in Heat and Thermodynamics.

The results from Table 15 showed the results of the Crosstabulation and chi-square test between the females and the males, as well as their perceptions of the POE model-based strategy used during the study. The percentage count within sex (females and males) and within perceptions of the POE model-based teaching strategy indicated that majority (69.7%) of both female and male pre-service teachers had positive perceptions towards the model. This was an indication that in overall, majority of both genders positively perceived the use of the POE model during the study. Furthermore, the results also revealed that there was no statistical significant difference between the females and the males in their perceptions towards the POE model ($\chi^2 = 0.687$, $p > 0.05$). The null hypothesis (H_0: μ=0) was therefore not rejected.

These findings could be attributed to the fact that the POE teaching and learning strategy aligned well with the learning preferences of both female and male students, as it was engaging, interactive and promoted active learning. These factors tend to appeal to students regardless of their gender. Moreover, the POE model-based strategy may have been equally effective in promoting understanding and comprehension among both female and male students. Perhaps, the strategy effectively facilitated the Predict-Observe-Explain process and encouraged critical thinking, which led to positive perceptions among students irrespective of their gender. These findings are in agreement with studies by Ajayi and Ogbeba (2017), as well as Calsambis (2014), who found no significant gender differences in their studies. However, the findings seem to deviate from some previous studies that have revealed that there are gender differences in science education in terms of academic achievement, with females not achieving much compared to males, especially in the physical sciences (Zander et al., 2015; Lee & Burkam, 1996) Again, it also contradicts sighted research that have opined that factors such as learning environments, teacher attitudes, physiological orientation, self-efficacy beliefs, sex role models and orientation lead to gender disparities among learners (Tracy, 2016). Rather, the findings of the present study suggest that there was no gender difference in the students' perceptions towards the use of the POE model-based teaching strategy.

Finally, the results of this study tend to emphasise Ghana's vision of a stable, united, inclusive and prosperous country with opportunities for all (National Gender Policy, 2015), since the use of the POE model-based teaching strategy could be an effective teaching method for teaching science concepts to both females and males. The fact that there was no significant difference in the perceptions of males and females towards the teaching strategy could be a strong indication that it may be equally effective for both genders in their pursuit of science.

5.2 Summary of the Chapter

The chapter discussed the findings of the study in line with the research questions to draw inferences from these findings. The discussion of research question one revealed that the students' explanations to concepts were largely everyday and descriptive in nature, lacking the use of formal language of science. A discussion of research question two, however, saw a transition of the students' explanations from informal to formal language. This indicated an improvement in the nature of the students' explanations, suggesting that the use of the POE model had an effect on their learning. A similar trend was observed in the discussions of research questions three and four where it was observed that the quality of the students' explanations to concepts had improved. Their explanations to the scientific concepts which were mainly categorised as wrong and partial before the intervention of the POE model had transitioned largely to sound explanations after the intervention. A discussion of research question five revealed that overall, majority of the students' perceptions towards the use of the POE model-based teaching and learning strategy were positive. These positive perceptions were found in their cognitions, behaviour and emotions towards the use of the model. Last but not least, the study indicated that there was no statistically significant difference between females and males in their perceptions towards the use of the POE model. Hence, the null hypothesis of the study was not rejected.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.0 Overview

This chapter provides a summary of the study along with the conclusion that was drawn based on the data and suggestions that were made. In addition to this, it offers ideas for future research, and outlines the contributions made to the body of knowledge.

6.1 Summary

The purpose of this study was to determine the effect of the Predict-Observe-Explain (POE) model-based interactive teaching and learning strategy on the nature and quality of pre-service science teachers' explanations to concepts in science. Specifically, the study determined whether the POE model-based strategy had an effect on the nature and quality of the scientific explanations of Level 100 Integrated Science students of the University of Education, Winneba. The nature of an explanation was determined by a student's ability to construct scientific explanations using formal language of science (categorised into formal, causal, descriptive and everyday), while the quality of an explanation was determined by focusing on a students' in-depth advancement or depth of reasoning in providing a scientifically accurate explanation (categorised as sound, partial and wrong). After implementing the POE model-based strategy, the students' opinions were assessed to determine how they perceived the strategy. The questionnaire used in the study consisted of both closed-ended and open-ended items, and the students' responses to both items were categorised into three themes for analysis: Cognitive perceptions, Behavioural perceptions, and Emotional perceptions. The cognitive perception theme analysed students' perceptions of the impact of the POE strategy on their conceptual learning of science concepts. The behavioural perception theme assessed how the POE strategy affected students' attitudes towards science, while the emotional perception theme investigated how the strategy influenced students' interests and motivations in studying the science concepts. Six research questions and two hypotheses were formulated to guide the study.

The relevant theoretical underpinnings of the study: Bruner's Discovery Learning Theory, Piaget's Cognitive Development Theory and Vygotsky's Social Development Theory were thoroughly reviewed revealing their relevance to this study. The reviewed theories demonstrated the relevance of the POE model-based teaching strategy as an inquiry-based approach to learning that emphasised on how students actively constructed their own knowledge through an active, mental process of development. The theories indicated a shift from the traditional method of teaching to a more constructivist approach which allowed learners to make their own meaning through the POE model-based interactive teaching. The conceptual framework (ideas) of the study indicated how the researcher played key roles in planning and facilitating learning by employing interactive teaching strategies while applying the POE model in the teaching and learning process. Relevant related topics such as the Predict-Observe-Explain (POE) Strategy, Other Strategies of Teaching and Learning (Direct Instruction Model, Lecture Model, Cooperative Learning Model, and Inquiry-Based Learning Model), Scientific Explanations and Understanding of Concepts, Assessing Scientific Explanations and Gender implications of the use of the POE model in teaching and learning science were reviewed and discussed in the context of the study. Empirical studies conducted on the POE strategy were also reviewed in line with the present study. The study's philosophical undertone was discussed as well.

The study adopted the action research design using Pre-tests and Post-tests design on an intact group of Level 100 Integrated Science students, purposively sampled for the study. The study integrated both quantitative and qualitative approaches in the data collection and the analysis procedures, to enable triangulation of the results, and increase the credibility and validity of the findings of the study. Quantitative data was collected using Pre-tests and Post-tests scores of the students' explanations to the science concepts. The open-ended qualitative explanations of the students to both Pre-tests and Post-tests were numerically scored and stored as quantitative data. The Questionnaire on Perceptions of POE Model-based Teaching and Learning (QPPOE) was used to collect both quantitative and qualitative data on the students' perceptions of the teaching strategy. Data collected were analysed using descriptive statistics involving tables and graphs of frequency distribution of test scores to answer the research questions. The research hypotheses were tested using inferential statistics of the Chi-squared test. The following were the findings made based on the data collected and analysed:

1. Prior to the use of the POE model-based teaching and learning strategy, the pre-service science students' explanations to concepts were mainly informal (descriptive and everyday) in nature, expressed using common practical language. This suggested that the pre-service science teachers approached the learning of the science concepts largely on the basis of their everyday understanding of phenomena.
2. After the intervention of the POE model-based strategy, majority of the students' responses fell in the categories of formal and causal explanations. Thus, the pre-service teachers had made an improved transition from giving mainly informal to

formal explanations. This suggested that the use of the POE model-based teaching strategy gave the teachers opportunities to elaborate and expand on their conceptual understanding of the science concepts; and thus, were able to extend their explanations from simple everyday to detailed formal ones.

3. Quality of the students' explanations to concepts before the use of the POE model-based teaching and learning strategy was mainly partial and wrong; lacking correct scientific knowledge and deep reasoning. The explanations were largely characterised by scientifically inaccurate ideas, exhibiting contradictory and incoherent characteristics, and portraying minimal understanding of concepts. This suggested that the students lacked the necessary scientific knowledge to articulate the relationships between phenomena, and held misconceptions about the concepts of Heat and Thermodynamics from their previous studies.
4. After the use of the POE model-based strategy, the quality of the pre-service teachers' explanations improved, with majority of the responses categorised as sound explanations; that is, demonstrating a deeper understanding of scientific reasoning and accuracy. This suggested that using the POE model-based teaching strategy was a very useful teaching approach in helping the students to better understand the scientific concepts and improve the quality of their scientific explanations.
5. The students had positive perceptions of the use of the POE model-based strategy on their study of the science concepts. That is, on their conceptual understanding of the science concepts (cognitive perceptions), attitudes towards their study of the science concepts (behavioural perceptions) and interests (emotional perceptions) in

the study of the science concepts. This suggested that using the POE model-based strategy created a positive learning environment that promoted students' conceptual understanding, engagements, interests and motivation.

6. There was no significant difference between the perceptions of the females and males towards the use of the POE model-based teaching and learning strategy.
7. There was no statistically significant difference between the perceptions of males and females towards the use of the model-based teaching strategy. This suggested that the null hypothesis (H_0: μ=0) was not rejected.

6.2 Conclusion

Based on the findings presented, the study concluded that the use of the POE model-based teaching and learning strategy had a positive impact on the pre-service science teachers' use of formal language, conceptual understanding and scientific reasoning, improving the nature and quality of their scientific explanations to concepts. The intervention helped the pre-service teachers to transition from giving mainly informal explanations to formal explanations, as well as wrong and partial explanations to sound explanations, thus improving the overall nature and quality of their explanations. Moreover, the students had positive perceptions towards the use of the POE model-based strategy, indicating that it created a positive learning environment that promoted conceptual understanding, scientific reasoning, interactive engagement, and motivation towards science. Finally, there was no significant difference between the perceptions of females and males towards the use of the model-based teaching strategy; implying that there is no need for separation of instructional strategy for females and males since the POE model-based strategy could be used successfully.

In overall, the study provides evidence to support the use of the POE model-based teaching and learning strategy as an effective approach for improving the teaching and learning of science, and enhancing students' understanding of scientific concepts.

6.3 Recommendations

Based on the findings and conclusion from the study, the following are some recommendations:

1. Science teacher educators in the Faculty of Science, and specifically of the Integrated Science Education Department of the University of Education, Winneba should adopt the POE model-based teaching and learning strategy in the training of pre-service science teachers, to inculcate the use of formal language of science and promote a deeper understanding of scientific concepts, to enhance the nature and quality of scientific explanations given by future science teachers.
2. Pre-service science teachers of the Department of Integrated Science Education of the University of Education, Winneba should be encouraged to use the POE model-based teaching and learning strategy as a teaching approach, to improve their own use of formal language of science, and enhance their deeper understanding of scientific concepts to improve the nature and quality of scientific explanations they give to their students.
3. Teacher training institutions such as Teacher Training Universities and Colleges of Education should review and revise their science teacher training curriculum to incorporate more active learning strategies like the POE model-based strategy, to promote a deeper understanding of scientific concepts and improve the nature and quality of scientific explanations given by pre-service science teachers.

4. The POE model-based teaching and learning strategy is not gender sensitive therefore both female and male students should be included in activities involving the strategy in their science classrooms to promote both genders' use of formal language, conceptual understanding and scientific reasoning.
5. Future studies should explore the effectiveness of the POE model-based teaching and learning strategy on the teaching and learning of other science concepts and related subjects, as well as in different contexts, to further enhance its applicability in science education.
6. Further studies should investigate the factors that affect the implementation and effectiveness of the POE model-based teaching and learning strategy in science education at the University and College of Education levels; such as the availability of resources, teacher and student factors, and institutional factors.

6.4 Suggestions for Further Research

Based on the findings of this study, the following are some suggestions for further research:

1. Studies should be conducted to investigate the effectiveness of the POE model-based teaching and learning strategy on the conceptual understanding, nature and quality of scientific explanations of students in other science concepts apart from Heat and Thermodynamics.
2. Similar studies should be conducted with a larger sample size and different demographic groups to investigate the generalisability of the findings.
3. Compare the effectiveness of the POE model-based teaching and learning strategy with other teaching approaches in improving students' conceptual understanding, scientific explanations, attitudes, and interests towards the study of science.

4. Investigate the factors that may influence the effectiveness of the POE model-based teaching and learning strategy, such as prior knowledge of science concepts, teaching experience, and teacher training.
5. Conduct a study that investigates the effectiveness of the POE model-based teaching and learning strategy on students with different learning styles and abilities.
6. Investigate the students' perceptions of the POE model-based teaching and learning strategy in relation to their confidence in their ability to explain scientific concepts.
7. Investigate the effectiveness of combining the POE model-based teaching and learning strategy with other teaching strategies, such as project/problem-based learning, on students' conceptual understanding and scientific explanations.

6.5 Contribution to Knowledge

This study has contributed to research and knowledge in science education by demonstrating the effectiveness of using a POE (Predict, Observe, and Explain) model-based teaching and learning strategy in improving pre-service science teachers' conceptual understanding, scientific reasoning, nature and quality of scientific explanations on some concepts of Heat and Thermodynamics. The study's findings suggest that the POE model-based strategy was effective in promoting a positive learning environment that promoted students' engagement, interests, and motivation in the study of science concepts. It also provided insights into the perceptions and attitudes of pre-service science teachers towards the use of the POE model-based teaching and learning strategy. Furthermore, the study showed that there was no significant difference between the perceptions of male and female students towards the use of the POE model-based teaching and learning strategy.

Consequently, this study provides insights into the use of innovative teaching strategies in enhancing the quality of science education, particularly for pre-service teachers. The findings can be used to inform science educators and policy-makers on effective approaches to science teaching and learning. Additionally, this study provides a basis for further research into the use of POE model-based teaching strategies in other areas of science education and in different educational contexts.

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Appendix A – Pre-Test and Post-Test 1

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Pre-test (Heat and Temperature)

Index number 1: …………………………………..

Index number 2: …………………………………..

Index number 3: …………………………………..

Please answer all questions.

1. In a glass of water at room temperature, do all the molecules have the same speed? Explain your answer.

   ……………………………………………………………………………………
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   ……………………………………………………………………………………
   ……………………………………………………………………………………

2. Adding the same amount of heat to two different objects does not necessarily produce the same increase in temperature. Why not?

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   ……………………………………………………………………………………
   .

3. Briefly explain which has a greater amount of internal energy – an iceberg or a cup of hot water?

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   ……………………………………………………………………………………
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Post-test (Heat and Temperature)

Index number 1: …………………………………..

Index number 2: …………………………………..

Index number 3: …………………………………..

Please answer all questions.

1a. Consider two glasses A and B. Glass A is filled with water and glass B is half-full, with the water in both glasses being at the same temperature. In which glass are the water molecules moving faster?

A. Glass A
B. Glass B
C. Both Glass A and Glass B
D. None of them

Please explain your answer:

………………………………………………………………………………………………
………………………………………………………………………………………………

1b. In which glass is there greater internal energy?

A. Glass A
B. Glass B
C. Both Glass A and Glass B
D. None of them

Please explain your answer:

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2. Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?

A. a molecule in a gram of ice water

B. a molecule in a gram of steam

C. Both

Please explain your answer:

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Appendix B – Marking Scheme for Pre-Test and Post-Test 1

Marking Scheme - Pre-test (Heat and Temperature)

1. In a glass of water at room temperature, do all the molecules have the same speed? Explain your answer.

   Yes, the same average speed, but not the same instantaneous speed. At any moment, molecules with the same average speed can have enormously different instantaneous speeds.

2. Adding the same amount of heat to two different objects does not necessarily produce the same increase in temperature. Why not?

   Different substances have different thermal properties due to differences in the way energy is stored internally in the substances. When the same amount of heat produces different changes in temperatures in two substances of the same mass, we say they have different specific heat capacities.

3. Briefly explain which has a greater amount of internal energy – an iceberg or a cup of hot water?

   The hot coffee has a higher temperature, but not a greater internal energy. Although the iceberg has less internal energy per mass, its enormously greater mass gives it a greater total internal energy than that in the small cup of coffee.

Post-test (Heat and Temperature)

1a. Consider two glasses A and B. Glass A is filled with water and glass B is half-full, with the water in both glasses being at the same temperature. In which glass are the water molecules moving faster?

E. Glass A
F. Glass B
G. Both Glass A and Glass B

H. None of them

Having the same temperature indicates that the average kinetic energy of the molecules in both glasses is the same.

1b. In which glass is there greater internal energy?

E. Glass A

F. Glass B

G. Both Glass A and Glass B

H. None of them

Glass A has twice the number of molecules compared to glass b, hence the total kinetic energy of the molecules will be higher, giving it a greater internal energy.

4. Which has more kinetic energy – a molecule in a 1g of ice water or a molecule in a 1g of steam?

D. a molecule in a gram of ice water

E. a molecule in a gram of steam

F. Both

If a body has a high temperature, each of its molecules has, on the average, a large amount of kinetic energy.

Appendix C – Pre-Test and Post-Test 2

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Pre-test (Thermal Expansion)

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Please answer all questions.

1. If you have a pair of drinking glasses that are stuck together, what is the easiest way of separating them with water at different temperatures in the inner and outer surfaces of the glasses? Explain your answer.

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2. Why is it important that a key and its lock should be made of the same or similar materials?

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3. Why does ice form at the surface of a body of water instead of at the bottom?

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Post-test (Thermal Expansion)

Index number: ……………………………………………………………..

Index number: ……………………………………………………………..

Index number: ……………………………………………………………..

Please answer all questions.

1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?
   A. Mercury has a lower rate of expansion than glass
   B. Mercury has a higher rate of expansion than glass
   C. Both mercury and glass have equal rates of expansion

Please explain your answer:

…………………………………………………………………………………………
…………………………………………………………………………………………

2. When the temperature of ice-cold water is slightly increased, it undergoes …………..
   A. A net contraction
   B. A net expansion
   C. Both contraction and expansion at the same time
   D. No change

Please explain your answer:

…………………………………………………………………………………………
…………………………………………………………………………………………

3. Suppose that you cut a small gap in a metal ring. If you were to heat the ring, would the gap

   A. Increase,

   B. Decrease or

   C. Remain the same?

   Please explain your answer:

   ……………………………………………………………………………………

Appendix D – Marking Scheme for Pre-Test and Post-Test 2

Pre-test (Thermal Expansion)

Please answer all questions.

1. If you have a pair of drinking glasses that are stuck together, what is the easiest way of separating them with water at different temperatures in the inner and outer surfaces of the glasses? Explain your answer.

The easiest way is to first pour water of very low temperature into the inner glass (the molecules of the glass will contract), and then heat the outer glass with water of very high temperature (the molecules of the outer glass will expand). As the inner glass contracts and the outer glass expand, a gap will be created between them, and a gentle twist will separate them.

2. Why is it important that a key and its lock should be made of the same or similar materials?

If both key and lock are made of same or similar materials, they would have the same coefficient of thermal expansion, and as such would match each other to function effectively.

3. Why does ice form at the surface of a body of water instead of at the bottom?

Due to the anomalous expansion of water, water begins expanding and becomes less dense as it gets colder. Thus, below 4° Celsius, water becomes less dense, causing water about to freeze to float to the top. As a result, close to freezing, colder water floats to the top and the warmer water sinks to the bottom.

Post-test (Thermal Expansion)

Please answer all questions.

1. When a mercury thermometer is heated, the mercury expands and rises in the thin glass tube. What does this indicate about the relative rates of expansion for mercury and glass?

   D. Mercury has a lower rate of expansion than glass

E. Mercury has a higher rate of expansion than glass

F. Both mercury and glass have equal rates of expansion

Please explain your answer:

The relative rates of expansion for mercury and glass are different (each substance has a different coefficient of expansivity) for a given change in temperature. Mercury rising in the glass tube indicates that it has a higher rate of expansion than glass for the same temperature change.

2. When the temperature of ice-cold water is slightly increased, it undergoes …………..

E. A net contraction

F. A net expansion

G. Both contraction and expansion at the same time

H. No change

Please explain your answer:

It will contract due to the characteristics in the structure of water molecules. Water is an exceptional case while considering the expansion and contraction of a liquid. Presence of hydrogen bond is also a reason for this unusual behaviour of water molecules. And the density of ice is less than liquid water and it will float on water. This is also a part of the exceptional behaviour of water molecule.

Conclusion: If the temperature of ice-cold water is increased slightly, a net contraction will be observed due to its exceptional properties of structure.

3. Suppose that you cut a small gap in a metal ring. If you were to heat the ring, would the gap

D. Increase,

E. Decrease or

F. Remain the same?

Please explain your answer:

Both the gap and the hole will become wider as if there is neither gap nor hole. This is because every part (length, gap, etc.) of the ring expands proportionally when heated uniformly.

Appendix E – Pre-Test and Post-Test 3

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Pre-test (Specific Heat Capacity)

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Please answer both questions.

1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

……………………………………………………………………………………………………..

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2. On a visit to the beach on a hot sunny day, the concrete pavement is extremely hot and unbearable, the beach sand is hot but the sea is comfortably cool. However, upon a return visit at night, the concrete pavement is very cold, the beach sand cool and the sea very warm. Give a brief account to explain what brings about these experiences.

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3. A certain quantity of heat is supplied to both 5kg of iron and 5kg of water. Briefly explain which one will undergo the greater change in temperature.

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Post-test (Specific Heat Capacity)

Index number: ……………………………………………………………………..

Index number: ……………………………………………………………………..

Index number: ……………………………………………………………………..

Please answer all questions.

1. A whole chicken is wrapped in aluminium foil and grilled in an oven at a temperature of 350^0C for 50 minutes. Immediately the package is brought out of the oven, which would be easier to handle?

A. The aluminium foil

B. The chicken

C. None of them

D. Both of them

Please explain your answer:

…………………………………………………………………………………………………
…………………………………………………………………………

2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?

   A. Metal pan

   B. Cold water

   C. Both metal pan and cold water will absorb the same amount of heat at the same time

   D. There is not enough information to tell

   Please explain your answer:

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…………………………………………………………………………………………………

3. When heat is added to a substance some goes partly into the translational kinetic energy of its molecules, which directly increases temperature. For some substances, greater portions of heat also go into vibrations and rotations of the molecules.

Would you expect materials in which a lot of energy goes into non-translational molecular motions to have a

A. High specific heat capacity

B. Low specific heat capacity

Please indicate your reasoning:

……………………………………………………………………………………………
……………………………………………………………………………………………..,,

Appendix F – Marking Scheme for Pre-Test and Post-Test 3

Pre-test (Quantity of Heat)

Please answer all questions.

1. In the olden days during cold nights it was common practice to bring a hot object to bed with you. Which would keep you warmer throughout the cold night – a 10kg hot iron block or a 10kg jug of hot water both at the same temperature? Explain your answer.

The 10kg jug of water. This is because since water has a higher specific heat capacity than iron, the water will retain its heat energy for long and thus keep the body warm much longer than the iron block.

2. On a visit to the beach on a hot sunny day, the concrete pavement is extremely hot and unbearable, the beach sand is hot but the sea is comfortably cool. However, upon a return visit at night, the concrete pavement is very cold, the beach sand cool and the sea very warm. Give a brief account to explain what brings about these experiences.

This is due to the different specific heat capacities of water, sand and concrete in the order water > sand > sea. Water will warm up slowly and retain its heat for a longer period than sand and concrete.

3. A certain quantity of heat is supplied to both 5kg of iron and 5kg of water. Briefly explain which one will undergo the greater change in temperature.

5kg of iron will undergo a greater change in temperature compared to 5kg of water due to the low SHC of iron. Thus, for the same temperature iron will undergo a greater change in temperature than water.

Post-test (Quantity of Heat)

1. A whole chicken is wrapped in aluminium foil and grilled in an oven at a temperature of 350^0C for 50 minutes. Immediately the package is brought out of the oven, which would be easier to handle?

E. The aluminium foil

F. The chicken

G. None of them

H. Both of them

Please explain your answer:

The aluminium foil would be easier to handle because it has a lower SHC and will quickly loose the heat compared to the chicken which contains water, and thus has a high SHC. Chicken will retain the heat for long and would be difficult to handle.

2. When a 200g metal pan containing 200g of cold water is removed from the refrigerator and set on a table, which will absorb more heat from the room?
   E. Metal pan

   F. Cold water

   G. Both metal pan and cold water will absorb the same amount of heat at the same time

   H. There is not enough information to tell

   Please explain your answer:

Since the specific heat of the water (liquid or even frozen) is much bigger than the specific heat of about any common metal than the water will absorb more heat than the pan.

3. When heat is added to a substance some goes partly into the translational kinetic energy of its molecules, which directly increases temperature. For some substances, greater portions of heat also go into vibrations and rotations of the molecules. Would you expect materials in which a lot of energy goes into non-translational molecular motions to have a

   C. High specific heat capacity

   D. Low specific heat capacity

   The more ways a molecule can move internally, the more energy it can absorb to excite these internal motions. This greater capacity for absorbing energy makes it have a higher specific heat capacity.

Appendix G – Pre-Test and Post-Test 4

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Pre-test (Heat Transfer - Conduction)

Index number: ---
Index number: ---
Index number: ---

Please answer all questions.

1. On a cold day, a metal knob feels colder than the wooden door. Explain why this is so?

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……………………………………………………………………………………………
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2. Explain why it is possible for you to put your bare hands in a hot oven for some time, but extremely dangerous to touch the metal sides of the oven.

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…………………………………………………………………………………………………

3. If you hold one end of a piece of metal against a piece of ice, the end in your hand soon becomes cold. Does this mean that cold flows from the ice to your hand? Defend your answer.

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Post-test Lesson (Heat Transfer - Conduction)

Index number: ---
Index number: ---
Index number: ---

Please answer all questions.

1. Explain the purpose of a layer of copper or aluminium placed at the bottom of stainless steel cookware.

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…...……………...………………………………………………………………………………

…………..………………………………………………………………………………………

……A boy simultaneously picks up two cartons of drink, a cold one from the refrigerator and a warm one that has been sitting on a table for some time: Compared to the warm carton, the cold carton …….........

A. contains more cold
B. contains less heat
C. is a poorer heat conductor
D. conducts heat more rapidly from the boy's hand
E. conducts cold more rapidly to the boy's hand

Explain your choice of answer:

…………………………………………………………………………………………………

………………………………………………………..……………………………………

…A girl expresses that she does not like sitting on the metal chairs in the classroom because <u>they are colder than the plastic ones</u>. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which of the students do you agree with and why?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Appendix H – Marking Scheme for Pre-Test and Post-Test 4

Pre-test (Heat Transfer - Conduction)

1. On a cold day, a metal knob feels colder than the wooden door. Explain why this is so?

A metal is a better conductor than wood, thus, heat will flow from the body (at a higher temperature) to the metal knob (at a lower temperature) at a faster rate than from the body to the wood.

2. Explain why it is possible for you to put your bare hands in a hot oven for some time, but extremely dangerous to touch the metal sides of the oven.

Air is a bad conductor of heat while metal is a good conductor of heat.

3. If you hold one end of a piece of metal against a piece of ice, the end in your hand soon becomes cold. Does this mean that cold flows from the ice to your hand? Defend your answer.

No, heat flows from your hands to the ice through the metal (a good conductor of heat)

Post-test Lesson (Heat Transfer - Conduction)

1. Explain the purpose of a layer of copper or aluminium placed at the bottom of stainless steel cookware.
2. A boy simultaneously picks up two cartons of drink, a cold one from the refrigerator and a warm one that has been sitting on a table for some time: Compared to the warm carton, the cold carton …….........
   F. contains more cold
   G. contains less heat
   H. is a poorer heat conductor
   I. conducts heat more rapidly from the boy's hand
   J. conducts cold more rapidly to the boy's hand

Explain your choice of answer:

3. A girl expresses that she does not like sitting on the metal chairs in the classroom because they are colder than the plastic ones. Four students give her reasons as follows:

Student A: They are colder because metal is naturally colder than plastic.

Student B: They are not colder; they are at the same temperature.

Student C: They are not colder; the metal ones just feel colder because they are heavier.

Student D: They are colder because metal has less heat to lose than plastic.

Which student do you agree with and why?

Appendix I – Pre-Test and Post-Test 5

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Pre-test (Convection & Radiation)

Index number: ……………………………………………………………..

Index number: ……………………………………………………………..

Index number: ……………………………………………………………..

Please answer all questions.

1. Energy is radiated by all objects. However, it is impossible to see these objects in the dark. What accounts for this?

------What does the high specific heat of water have to do with convection currents in the air at the seashore? Explain your answer.

------In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

Post-test Lesson (Convection & Radiation)

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Index number: ………………………………………………………………..

Please answer all questions.

1. Ice cubes float in a glass of iced tea. Would the melting of the cubes be faster or slower if they were placed at the bottom of the tea?
   A. Faster
   B. Slower

Explain your answer.

----

2. Ceiling fans can make you feel cooler in a warm room. Do they reduce the room temperature?
   A. Yes
   B. No

Please explain your answer:

----

3. A boy says his mother mostly bakes bread on the top shelf inside the oven because it is hotter at the top than at the bottom.

Student A says that it is hotter at the top because heat rises.

Student B says that it is hotter because metal trays concentrate the heat.

Student C says it is hotter at the top because the hotter the air the less dense it is.

Student D disagrees with them all and says that it is not possible to be hotter at the top.

Which student do you think is right? Give the reasoning for your choice.

Appendix J – Marking Scheme for Pre-Test and Post-Test 5

Pre-test (Convection & Radiation)

1. Energy is radiated by all objects. However, it is impossible to see these objects in the dark. What accounts for this?

At room temperature, energy radiated is primarily in the infrared region of electromagnetic radiation. Our eyes are only sensitive to visible light and cannot detect this radiation. Hence we cannot see the objects in a dark room.

2. What does the high specific heat of water have to do with convection currents in the air at the seashore? Explain your answer.

Because of the high specific heat of water, sunshine warms water much less than it warms land. As a result, air is warmed over the land and rises. Cooler air from above the cool water takes its place and convection currents are formed. If land and water were heated equally by the Sun, such convection currents (and the winds they produce) would not be established.

3. In a still room, smoke from a candle will sometimes rise only so far, not reaching the ceiling. Explain why.

The smoke, like hot air, is less dense than the surroundings and is buoyed upward. It cools when it makes contact with the surrounding air and becomes denser. When its density becomes equal to the surrounding air, its buoyancy and weight balances out and the rising ceases.

Post-test (Convection & Radiation)

1. Ice cubes float in a glass of iced tea. Would the melting of the cubes be faster or slower if they were placed at the bottom of the tea?

   C. Faster
   D. Slower

Explain your answer.

Ice cubes will cool less if they were on the bottom because of the lack of convection process. Water at 4° C is denser than ice. Ice will cool the liquid in the surface, and the

result will be that the dense liquid will fall to the bottom of the glass, while the hot liquid will rise above.

2. Ceiling fans can make you feel cooler in a warm room. Do they reduce the room temperature?
   C. Yes
   D. No

Ceiling fans do not reduce the temperature in the room but merely circulate air by pushing down cooler denser air while allowing warmer less dense air to rise, making you feel cooler.

Ceiling fans can also help to make a room seem cooler by redistributing air. Usually, hot air rises, while cool air settles in the lower part of a room. A ceiling fan can help to pull cold air higher up, so it circulates around your face instead of your feet. These effects all combine to help cool you down even if the room temperature remains high.

3. A boy says his mother mostly bakes bread on the top shelf inside the oven because it is hotter at the top than at the bottom.

Student A says that it is hotter at the top because heat rises.

Student B says that it is hotter because metal trays concentrate the heat.

Student C says it is hotter at the top because the hotter the air the less dense it is.

Student D disagrees with them all and says that it is not possible to be hotter at the top.

Which student do you think is right? Give the reasoning for your choice.

Student C: Warm air is lighter than cold air because its particles have more heat energy, which results in the increase in distances between the molecules. This decreases the density, and hence makes it lighter than cold air. Thus it will rise to the top in the oven.

Appendix K - Questionnaire on Perceptions of Poe Model-Based Teaching and Learning (QPPOE)

University of Education, Winneba

Faculty of Science Education

Department of Integrated Science Education

Questionnaire on Perceptions of POE Model-based Teaching and Learning (QPPOE)

Instructions: Dear Student, this questionnaire is intended to solicit your opinions about the use of the POE model-based teaching strategy. Select one level of agreement for each statement to indicate how you will feel. Kindly respond to the questions candidly. Please be assured that your answer will remain confidential, and no part of this questionnaire will be used against you in your assessments regarding the course. This should take about 20 minutes of your time.

SD =Strongly disagree, D= Disagree, U=Undecided, A=Agree, SA= Strongly agree

Perceptions of the POE Strategy on Science Teaching and Learning	**SA**	**A**	**N**	**D**	**SD**
1. The POE model based teaching and learning helped me become aware of the importance of science involved in my daily life.					
2. The POE model based teaching and learning made my understanding of science concepts easier.					
3. The POE model based teaching and learning made me prepare before coming to class by doing the pre-reading assignments.					
4. The POE model based teaching and learning made me more enthused about studying science.					

5. The POE model based teaching and learning made me change my behaviour during class in a more positive way.					
6. The POE model based teaching and learning has influenced my perception on science in a positive way.					
7. The POE model based teaching and learning did not make me feel discouraged during science lessons.					
8. The POE model based teaching and learning did not confuse me in the course of study.					
9. Through the POE model based teaching and learning I was able to relate content taught to everyday life.					
10. The POE model based teaching and learning made me more engaged with my classmates.					
11. Through the POE model based teaching and learning I learnt from my colleagues.					
12. The POE model based teaching and learning made the learning of science fun.					
13. The POE model based teaching and learning made learning tedious for me.					

14. Was your perception of science after encountering the POE model-based teaching and learning positive or negative?

15. Please explain what factors led to your positive perceptions.

16. Please explain what factors led to your negative perceptions.

17. Since you have experienced both traditional and POE model based strategies, which one of these two do you prefer?

18. Why do you prefer the choice in 17 above? (Please be more specific)

19. Is there anything else that you would like to say about your perceptions of this course and the POE model based teaching and learning?

Appendix L - Content Validity Index (CVI) For QPPOE

4-Point Likert Scale for CVI of Questionnaire

Item No.	Highly Relevant/ Represented	Relevant/ Represented	Some what Relevant/Represented	Not Relevant/Represented

Results after the experts reviewed the questionnaire items:

Number of Experts: 3

Experts/Ratings of Items	**Number of items rated Highly Relevant/Relevant (A)**	**Total number of questionnaire Items (B)**	**CVI of Items (A/B)**
Expert 1	15	19	0.79
Expert 2	17	19	0.89
Expert 3	17	19	0.89

Total CVI of questionnaire = 0.79+0.89+0.89/3 = **0.86**

Appendix M – Students' Assessment Scores on Pre-Tests and Post-Tests

Index Number/ Groups	Assessment Quality	Pre-tests Scores on Quality of Explanations					Assessment Quality	Post-tests Scores on Quality of Explanations					Assessment Nature	Pre-tests Scores on Nature of Explanations					Assessment Nature	Post-tests Scores Nature of Explanations				
		1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**
220015884		0	1	2	3	2		2	2	1	2	2		0	2	1	2	2		2	2	2	3	2
220026310																								
220021372																								
202147386		1	2	2	2	2		2	1	2	2	2		1	2	1	2	1		2	1	2	3	2
220020006																								
220029658																								
220005850		1	1	2	2	2		1	1	1	3	2		1	1	1	3	1		1	1	1	3	2
220004747																								
220000304																								
220030173		1	2	1	0	2		2	2	2	2	2		2	2	1	3	2		1	1	3	3	2
202111220																								
220016825																								
220007648		1	2	1	2	1		2	1	2	3	2		1	2	2	3	2		1	1	2	3	3
220011764																								
220026331																								
220027286		1	2	2	2	2		3	2	2	2	3		2	2	1	1	1		1	2	3	3	2
220033176																								

202132865																								
202148887		1	2	1	2	1		2	1	2	1	3		2	2	1	3	2		1	1	2	2	3
220028116																								
220004855																								
220031594		1	2	2	1	1		3	1	2	3	3		1	3	2	3	2		2	2	1	3	2
220028945																								
220019576																								
220017835		0	2	0	1	1		2	0	2	2	3		0	2	1	2	1		2	0	2	3	3
202135240																								
220010839																								
220005318		1	2	0	2	1		2	1	2	2	3		1	2	0	1	1		1	1	2	3	2
220012756																								
220006436																								
220017976		1	2	1	0	1		2	1	2	3	3		1	2	1	1	2		1	2	3	3	3
220014416																								
220002006																								
220020143		0	1	1	0	1		3	1	3	2	2		0	1	1	2	2		1	2	2	2	3
220032100																								
220032147																								
220030011		0	2	1	0	1		2	2	3	2	2		0	3	1	3	1		2	2	3	3	2
220018171																								
220012029																								
220006944		0	2	1	1	2		3	2	2	3	2		3	3	1	2	2		3	2	2	3	2
220024300																								
220012623																								
220029967		1	2	1	2	2		3	1	3	2	3		1	2	1	2	2		2	1	3	3	2
220006749																								
220000634																								
202112214		1	1	1	1	0		2	2	3	2	3		1	1	0	2	1		3	2	2	1	3
202111842																								
220026998																								

202133238		1	1	1	1	0		2	1	2	3	3		1	1	0	2	1		2	1	2	2	3
202111148																								
220005990																								
220031592		1	2	1	0	1		1	1	2	2	3		1	2	2	2	1		3	3	2	3	2
220011238																								
220001025																								
220030749		1	2	0	2	1		2	1	3	2	3		1	2	2	2	1		2	2	1	3	2
220019541																								
220005400																								
220003239		1	1	1	1	1		1	1	2	2	3		1	1	1	2	2		3	2	2	2	3
202108953																								
220019318																								
220027020		0	1	2	1	1		3	1	3	3	2		0	1	1	2	1		1	2	2	3	3
220014775																								
220032515																								
220018533		0	1	2	1	1		2	1	2	2	2		1	1	1	1	1		2	1	3	3	2
220002249																								
220009116																								
220011002		1	2	2	1	2		2	1	3	2	3		1	2	1	2	2		1	1	2	2	2
220001468																								
220017898																								
220006289		1	1	1	2	2		2	1	3	2	2		2	1	0	2	2		1	2	2	3	2
220017517																								
220024069																								
220002552		0	1	2	0	1		2	2	3	3	2		1	1	1	2	2		2	3	3	2	3
202124311																								
220007169																								
220031455		1	1	1	1	2		3	3	3	2	2		1	1	1	2	2		2	1	3	2	2
220004007																								
220018142																								
220014129		0	1	2	1	1		2	3	3	2	2		0	1	1	2	1		2	3	2	3	3
220001837																								

220031849																								
220030820		0	2	1	1	2		2	3	2	2	2		0	3	1	2	2		2	3	3	3	2
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220009295																								
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220017459																								

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220013955																								

Appendix N – Reliability Analysis of Questionnaire Items

Case Processing Summary

		N	%
Cases	Valid	244	97.2
	Excluded[a]	7	2.8
	Total	251	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.798	.822	14

Appendix O – A Sample Lesson Plan of the Study

Course Code: INS 123

Course Title: Heat and Thermodynamics

Specific Topic: Heat and Temperature

Level: 100

Lesson Duration: 3 hours

References:

Hewitt, P. G. (2015). Conceptual Physics (12th Ed.). San Francisco, CA: Addison Wesley

Cutnell, J. D., & Johnson, K. W. (2007). Physics (7th Ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Serway, R. A., Vuille, C., & Faughn, J. S. (2008). College Physics Vol. I (8th ed.). Belmont, CA: Thomson Higher Education

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Learning Objectives:

By the end of the lesson, the student will be able to:

1. Explain concepts such as heat, temperature, total kinetic molecular energy, average kinetic energy, thermal energy, internal energy, and many more using appropriate formal language of science.
2. Provide scientifically accurate explanations to concepts such as heat, temperature, total kinetic molecular energy, average kinetic energy, thermal energy, internal energy, and many more.
3. Exhibit sound or deep scientific reasoning in explaining concepts such as heat, temperature, total kinetic molecular energy, average kinetic energy, thermal energy, internal energy, and many more.

Relevant Previous Knowledge:

Students have ideas about the topic from their previous studies at the second cycle institutions. Again, they have done their pre-preparatory reading assignments and as such have some knowledge on Heat and Temperature.

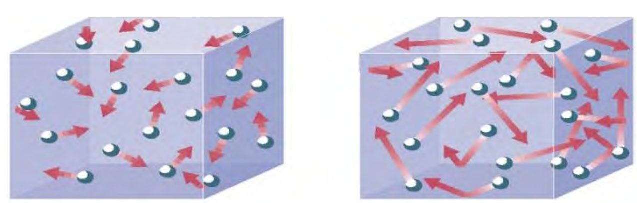
Teaching and Learning Materials:

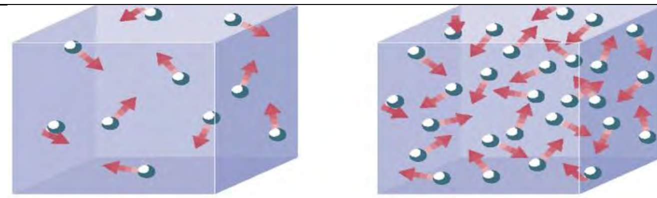
- Conceptual Physics (Hewitt, 2015) Textbook
- Projector
- Laptop
- Softcopy of Conceptual Physics (Hewitt, 2015)

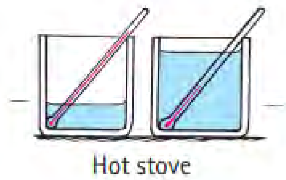
Lesson Presentation:

Phase 1 – Prediction (Pre-intervention)			
Activity	**Duration**	**Facilitator Role(s)**	**Students Role(s)**
Brief introduction of lesson	5 minutes	Introduces lesson by directing students' attention to pre-reading assignment and the concepts to be discussed.	Mention concepts they learnt through the pre-reading assignments.
Conduct Pre-test	30 minutes	Distributes Pre-test papers to groups.	In mixed groups of 3-4 each, members of groups;

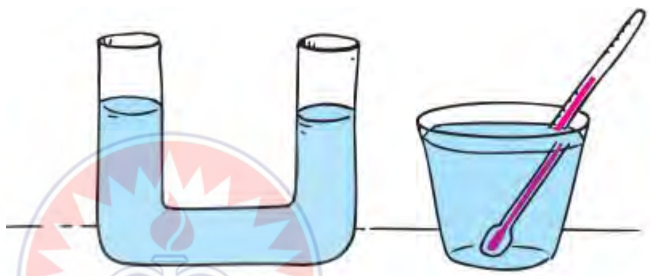
		Collects test papers after the Pre-test.	- Discuss ideas among themselves - Write appropriate answers to Pre-test (predict) based on their prior knowledge gained from the reading assignments.
Phase 2 – Observation (Intervention)			
Elicit ideas after Pre-test	10 minutes	Probes students' reasoning about the concepts after the Pre-test, by asking members of some groups to orally present ideas discussed and written during the Pre-tests. **Example of questions asked**:	Different group members orally present some ideas discussed and written during the Pre-tests.

		1. Do all molecules in a glass of water at room temperature have the same speed? What accounts for your answer? 2. Which of the following will have a greater amount of internal energy – an iceberg or a cup of hot water? How do you justify your answer?	
Lead Interactive Lesson	1 hour 30 minutes	Engages and leads students in a class discussion on the ideas or the concepts of the topic through the following procedure: - Uses PowerPoint presentations embedded with texts, pictures, illustrations, simulations from the Conceptual Physics (2015) textbook to engage the students in the teaching and learning process. Examples of slide presentations are below:  Longer arrows mean higher average speed. Temperature - measure of the average kinetic energy of the particles in a substance - particles in the box above have higher temperature - higher velocity = more KE = higher temperature.	Participates in student-student, student-teacher interactions to explain concepts of heat, temperature, total kinetic molecular energy, average kinetic energy, thermal energy, internal energy. Students to use the simulations

		 Boxes have same temperature - particles have same average velocity/KE - box above has more thermal energy - energy contained in a substance - more particles. Having the same temperature indicates that the average kinetic energy of the molecules in both glasses is the same.  There is more molecular kinetic energy in the container filled with warm water than in the small cupful of higher-temperature water. Different substances have different thermal properties due to differences in the way energy is stored internally in the substances. When the same amount of heat produces different changes in temperatures in two substances of the same mass, we say they have different specific heat capacities.	to explain the concepts of temperature using average kinetic energy of molecules. Discuss among them, led by facilitator to distinguish among average internal energy, total internal energy, thermal energy and temperature.



Although the same quantity of heat is added to both containers, the temperature increases more in the container with the smaller amount of water.



Temperature: Thermal Equilibrium

Just as water in the two arms of the U-tube seeks a common level (where the pressures at any given depth are the same), the thermometer and its immediate surroundings reach a common temperature (at which the average molecular KE is the same for both).

		- guides students to explain the various concepts of heat and temperature through interactive class discussions, debates and brainstorming. -guides students to reconcile predictions with observations of the ideas of the lesson. -allow some group representatives to provide feedback on their earlier predictions by explaining any discrepancies between their predictions and observations.	
Phase 3 – Explanation (Post-Intervention)			
Conduct Post-test	30 minutes	Distribute Post-test questions to groups to answer.	Students to make reconciliations between their predictions and observations and agree on the correct responses to the questions.

	15 minutes	Ends lesson by drawing on conclusions of the lesson.	Draw conclusions of the lesson by outlining salient science concepts of lesson.