AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

A PSYCHOMETRIC ASSESSMENT OF FACTORS CONTRIBUTING TO LEARNING CHALLENGES IN ATOMIC AND NUCLEAR PHYSICS AMONG SENIOR HIGH SCHOOL STUDENTS

JAMES CLARKE HAYFORD

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BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis, with the exception of quotation and references contained in published works which have been duly acknowledged; is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

James Clarke Hayford

Signature:…… Date:…….

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

Prof. Ebenezer Ekow Mensah (Principal Supervisor)

Signature:…… Date:…….

Dr. Eric Appiah-Twumasi (Co-supervisor)

Signature:…… Date:…….

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DEDICATION

This thesis is dedicated to my family, whose unconditional love and sacrifices have been the foundation of my academic journey. To my lovely wife Hellen Adu Bafo, thank you for instilling in me the value of education and perseverance. This work is also dedicated to Rev. Dr. Benjamin Adu Obeng, whose inspiration and encouragement have been a constant source of strength.

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LIST OF ABBREVIATIONS

Abbreviation	Full Meaning
AE	Assessment and Evaluation
AFA	Average Factor Analysis
AMOS	Analysis of Moment Structures
AVE	Average Variance Extracted
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CTT	Classical Test Theory
CR	Composite Reliability
CRDD	Curriculum Research and Development Division
EFA	Exploratory Factor Analysis
FGD	Focus Group Discussion
GES	Ghana Education Service
H□	Null Hypothesis
H□	Alternative Hypothesis
HTMT	Heterotrait–Monotrait Ratio
KMO	Kaiser–Meyer–Olkin Measure of Sampling Adequacy
LR	Learning Resources
MDC	Mathematical Demands Challenges

Abbreviation	Full Meaning
MoE	Ministry of Education
N	Sample Size
PSC	Problem-Solving and Application Challenges
RMSEA	Root Mean Square Error of Approximation
RWA	Relative Weight Analysis
SAI	Students' Attitude and Interest
SCT	Social Cognitive Theory
SD	Standard Deviation
SHS	Senior High School
SPSS	Statistical Package for the Social Sciences
TM	Teaching Method

ABSTRACT

This study investigated the challenges senior high school students in Atwima Nwabiagya Municipality face in learning atomic and nuclear physics, identifying contributing factors, their relative impact, and establishing psychometric evidence for the identified challenges and contributing factors. The exploratory sequential design, combining qualitative interviews and quantitative surveys was employed. Findings revealed significant challenges in conceptual understanding, problem-solving, and mathematics ematical demands, with a composite mean score of 4.26 (SD = 0.409). There were five factors that impacted students' challenges: the difficulty of the content, the manner/content in which it was delivered, the learning resources or materials used, the students' attitudes and interest, and the way in which they were assessed. A relative weight analysis showed that there were two most important factors. If we take into account that difficulty of content was the independent variable, the dependent variable was students' challenges, and then stage two was the relative weight. Thus, learning resources was shown to account for 49.04, p = 0.0187 and students' attitude/interest was 43.12, p = 0.0308 (41.8% of the variance accounted for). The "Students' Challenge Questionnaire" and "Factors Contributing to Students' Challenge Questionnaire" were developed and designed along with the result of the first study and showed excellent psychometric property. A seven-factor structure explained 66.979% of the variance, it had a reasonable empirical fit (CFI = 0.964, RMSEA = 0.052) and reasonable reliability (Cronbach's Alpha = 0.740 - 0.923). It was therefore concluded that students' struggles are multifaceted, stemming from both the inherent nature of the subject and external factors. Also, the developed and validated

instrument provides a reliable tool for diagnosing these challenges, offering a data-driven foundation for educators and policymakers to design targeted interventions. It was also recommended amongst others, that researchers and educators refine these instruments and explore interventions across diverse contexts to improve the learning of atomic and nuclear physics in Ghana.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter serves as the general introduction to the study and is structured into several key sections. It commences with the background of the study, followed by the problem statement. Subsequently, the chapter delineates the study's purpose, research objectives, and the research questions that directed the investigation. It also encompasses the justification and significance of the study. The chapter concludes with the study's scope and a concise outline of the overall organisation of the thesis.

1.1 Background to the Study

The field of physics is fundamental to understanding the universe, from the macroscopic scale of galaxies to the microscopic realm of subatomic particles. Among its various branches, atomic and nuclear physics stands out as a cornerstone of modern science, underpinning revolutionary technologies that have reshaped our society. Concepts such as radioactivity, fission, fusion, and the structure of the atom are not merely theoretical constructs but are the very principles that power nuclear energy, drive medical imaging and treatments, and enable countless technological innovations (Hussain et al., 2025; Ziyokhonovna, 2020).

Learners aspiring to careers in science, technology, engineering or medicine must appreciate and understand these concepts. It is also significant in fostering a scientifically knowledgeable community and using scientific knowledge and understanding to help solve complex societal issues. The central focus of science education curricula around the world is to teach and learn science well at the senior high school level so that students have a fundamental understanding of these concepts before studying more purpose-designed fields of study (Ministry of Education, 2023). To stress this area of education is to ignore unique ways that many students will be classified and this classification can affect that individual determined user's journey through specialists education contributing to scientific development.

Even though it is very important, teaching and learning atomic and nuclear physics in senior high school is very hard. According to Atlabachew (2021), the abstract and counter-intuitive nature of the subject matter, which often deals with phenomena not directly observable in daily life, presents a formidable hurdle for many students. In classical mechanics, principles can be illustrated through real physical experiments. In atomic and nuclear physics, however, one is required to think abstractly and be able to do some good mathematics ematics.

According to Zulkiffli et al. (2024), this disconnect between theory and tangible experience can lead to misconceptions, rote memorization without genuine understanding, and a general lack of confidence among students. These learning challenges are not merely minor academic problems; they frequently result in low

students' engagement (Achor et al., 2022), poor performance on standardized assessments (Assem et al., 2023), and being fearful of physics because it is perceived as being so difficult to understand (Tindan & Arthur, 2024). This creates a critical educational problem where a vital field of study is effectively made inaccessible to a large portion of the student population, thereby limiting the pipeline of future scientists and engineers who are so vital for a nation's progress.

The existing body of literature has touched upon some of the specific difficulties associated with learning atomic and nuclear physics, confirming that significant challenges persist. For instance, Morales and Tuzón (2020) found that Spanish secondary students held misconceptions about atomic structure and nuclear processes and were often influenced by media portrayals and emotional influences. Ejike et al. (2023) similarly illustrate that South African students had difficulty distinguishing between nuclear fission and fusion, and encountered difficulties with quantum behaviours. This suggests that the topic is highly abstract and that abstract concepts hinder student learning. Sartika and Humairah (2018) saw that 47.2% of high school students have a large misunderstanding, and Ewim et al. (2023) found that South African students have a low level of general knowledge and much incorrect understanding about nuclear energy.

However, despite these valuable contributions (Ejike et al., 2023; Ewim et al., 2023; Morales & Tuzón, 2020; Sartika & Humairah, 2018), there remains a notable gap in comprehensive, systematic research that not only identifies these challenges but also provides a robust, psychometrically validated tool for measuring the factors that account

for them, as well as the relative impact of these factors on the challenges. This gap is particularly pronounced within the Ghanaian educational context, where a thorough investigation into the specific challenges faced by senior high school students in atomic and nuclear physics is critically lacking. This leaves educators with a fragmented understanding of the problem, making it difficult to prioritise interventions and resources. Consequently, many teaching strategies are generic and may not be effectively targeting the root causes of the learning struggles specific to this subject, highlighting a critical need for a more granular and data-driven approach to addressing this educational issue.

A thorough understanding of the challenges students face is the first step toward developing effective and targeted interventions. If educators do not have a clear picture of what specific difficulties are most prevalent and what underlying factors are driving them, their efforts to improve student outcomes will be based on guesswork rather than evidence. The current study is therefore essential for providing this empirical foundation. By systematically identifying the precise challenges and their contributing factors, this research will equip teachers, curriculum developers, and policymakers with the information they need to design more effective pedagogical strategies, revise curriculum materials, and allocate resources more efficiently.

Furthermore, the implications of this study extend beyond the classroom. Sithole et al. (2017) argue that the persistent difficulties students face in a science subject contribute to a broader problem of science anxiety and a dwindling interest in Science, Technology, Engineering, and Mathematics ematics (STEM) fields. This has serious consequences for

a nation's ability to compete in the global economy and address pressing issues like climate change and public health, which rely on a skilled scientific workforce. By investigating and offering solutions to the specific challenges in atomic and nuclear physics, this research can help to demystify the subject and make it more accessible to a wider range of students.

A critical component of this research is the development and validation of a robust and reliable instrument to measure the challenges and the factors contributing to the students' challenges. Finding psychometric evidence for the reliability and validity of these factors underscores the methodological rigor required for such a study. Relying on anecdotal evidence or unvalidated survey tools can lead to flawed conclusions and ineffective interventions (Aithal & Aithal, 2020). Therefore, a significant contribution of this study is the creation of a standardised, scientifically sound tool that can be used to accurately and consistently measure the challenges and the various factors at play. This instrument will be a valuable asset for future research and for educators who wish to diagnose learning difficulties in their own classrooms. By ensuring the psychometric soundness of the instrument, the study guarantees that its findings are not only relevant but also trustworthy, providing a strong basis for evidence-based improvements in teaching practices and curriculum design.

Given the diverse research environment and the specific need for research in the Ghanaian context, this study will provide a comprehensive and evidence-based understanding of the challenges present in at atomic and nuclear physics education. The

study expects to provide the educational sector with data-drive insights and an authoritative instrument for helping in the improvement of teaching and learning through methodologically designed research. The aim of the findings are intended to advance academic knowledge while also having a tangible positive impact on student outcomes making the learning environment more effective and engaging as possible.

1.2 Statement of the Problem

The teaching and learning of atomic and nuclear physics is a fundamental component of science education, yet it is characterised by persistent challenges that lead to misconceptions, low student engagement, and poor academic performance (Zulkiffli et al., 2024). The abstract and complex nature of the subject matter is a considerable barrier for senior high school students and inhibits the development of a deep and meaningful understanding.

The West Africa Examination Council (WAEC) Chief Examiner report (CE) for physics for the past years (2020, 2021, 2022, 2023 and 2024) has been consistent in reporting that a lot of candidates sitting for the West Africa Senior Secondary Certificate Examination (WASSCE) physics paper were not able to handle the atomic and nuclear physics aspects very well. Thus, students' responses, ranging from absolute inability to inaccurate calculation of the half-life of a radioactive sample, the age of a bone specimen and the energy released in a nuclear reaction, are evidence of the complex and abstract nature of the concept. The CE report also points out that students showed weakness in describing how X-rays are produced and describing the process of power generation using a nuclear

reactor. It is therefore evident that there exists a problem in the teaching and learning of atomic and nuclear physics.

The persistent weaknesses reported by the WAEC Chief Examiner must be understood not merely as examination statistics, but as a call to action for policymakers, educators, and stakeholders to prioritise interventions in atomic and nuclear physics education. If Ghana wishes to make meaningful gains in performance in this area, it must address the general causes such as students' misconceptions, poor performance and lack of conceptual understanding. Failure to do this restricts students' achievement in school, limits them from taking upper-level science courses in the higher education systems, and consequently denies the country the potential for technological and economic progress.

The Chief Examiner's Reports highlight that challenges regarding the answering of atomic and nuclear physics have continually emerged, underscoring the need for systemic changes. Ghana, as a nation, must make deliberate attempts to build the capacity of teachers, improve the quality of instructional practices, and change students' interactions with these ideas; to avoid increasing the disparity between what the curriculum proposes and what students actually learn. It is evident that physics, and in particular atomic and nuclear physics, has many dimensions which combine to make it quite difficult to learn.

While some international studies have identified specific challenges and misconceptions regarding the study of physics and its related aspects (Ejike et al., 2023; Ewim et al., 2023; Morales & Tuzón, 2020; Sartika & Humairah, 2018), a significant gap still exists in

providing a comprehensive, systematic investigation into these challenges. This research gap is particularly pronounced within the Ghanaian educational context, where there is a dearth of extensive studies on the specific learning difficulties faced by senior high school students in atomic and nuclear physics. The current body of literature lacks a unified framework that transcends a mere identification of challenges and their underlying factors in teaching and learning physics to identifying empirical measures and assessing these underlying factors to determine their relative impact on the teaching and learning of physics.

This suggests that there is an important gap in providing an in-depth and systematic analysis of these challenges, as the existing literature lacks a coherent framework that describes the challenges, which can also be empirically informed to some degree, quantifying the relative importance of those challenges. There is therefore a need to identify and assess the specific factors that hinder students' understanding of atomic and nuclear physics. Therefore, the problem is not just a matter of identifying the challenges, but the absence of a comprehensive understanding of the challenges senior high school students in Ghana encounter in the teaching and learning of atomic and nuclear physics, the factors that account for these challenges, and the relative impact of these factors.

This study intends to fill this critical gap by developing and validating a reliable tool to measure these factors and providing a data-driven foundation for effective educational interventions. The study aims to investigate the psychometric properties of factors contributing to learning challenges in atomic and nuclear physics among the students of

Senior High School situated in the Atwima Nwabiagya Municipal in the Ashanti Region of Ghana, to inform instructional practices and interventions that can improve students' outcomes, particularly the learning challenges encountered by senior high school students in atomic and nuclear physics.

Addressing these challenges is not only critical for equipping students with the scientific literacy needed to thrive in a knowledge-driven global economy but also for empowering them to contribute meaningfully to national development. The lack of empirical data and a validated measurement tool leaves Ghanaian educators, curriculum developers, and policymakers without a clear understanding of the most critical challenges and the factors driving them. Consequently, interventions and pedagogical strategies are often generic and not specifically tailored to the root causes of student struggles. Without a scientifically sound understanding of what factors have the greatest influence, efforts to improve student outcomes in this vital subject may be misdirected and inefficient. To fill this critical gap, the study was designed to develop and validate a reliable tool for measuring factors that contribute to learning challenges in atomic and nuclear physics among Senior High School students, and to provide a data-driven foundation for effective educational intervention. Evidence from the literature has shown that little or no attempt has been made to empirically study the identified difficulties encountered by senior high school students in acquiring knowledge of atomic and nuclear physics. Similarly, the literature on empirical methodologies for assessing the relative impact of these factors is also minimal. This study is therefore timely and necessary as it seeks to address this long-

existed gap in Physics education. A study like this in Ghana is scarce (Aboagye et. al., 2025; Musah, 2022; Coffie et. al., 2020).

1.3 Purpose of the Study

The purpose of this study is to investigate the psychometric factors contributing to learning challenges in atomic and nuclear physics among senior high school students.

1.4 Objectives of the Study

The following were the specific objectives of the study:

1. To determine the challenges senior high school students, encounter in the teaching and learning of atomic and nuclear physics.
2. To ascertain the factors accounting for students' challenges in atomic and nuclear physics.
3. To determine the psychometric evidence to support the reliability and validity of the challenges and other contributing factors accounting for students' challenges in the teaching and learning of atomic and nuclear physics.
4. To determine the relative impact of factors accounting for students' challenges in the teaching and learning of atomic and nuclear physics.

1.5 Research Questions

The following research questions were stated to guide the study.

1. What challenges do senior high school students encounter in the teaching and learning of atomic and nuclear physics?

2. What factors account for students' challenges in the teaching and learning of atomic and nuclear physics?
3. To what extent is there psychometric evidence to support the reliability and validity of the challenges and other contributing factors accounting for students' difficulties in atomic and nuclear physics?
4. What is the relative impact of factors accounting for students' challenges in the teaching and learning of atomic and nuclear physics?

1.6 Research Hypothesis

Null Hypothesis (H□): There is no significant psychometric evidence to support the reliability and validity of the challenges and other contributing factors accounting for students' difficulties in atomic and nuclear physics.

Alternative Hypothesis (H□): There is significant psychometric evidence to support the reliability and validity of the challenges and other contributing factors accounting for students' difficulties in atomic and nuclear physics.

1.7 Justification of the Study

This study is justified by its direct and systematic approach to addressing several critical research gaps in the field of science education. While we currently acknowledge that existing international literature has highlighted the widespread challenges and misconceptions that senior high school students face in learning atomic and nuclear physics, there is a distinct lack of comprehensive research that unifies these findings by

identifying the full range of challenges, empirically measuring the factors that account for them, and determining their relative impact on student performance, especially in Ghana.

In addition, there is a major methodological shortcoming because there is no psychometrically validated and reliable measure to adequately assess the constructs of the challenges. Therefore, this study fills a major gap by developing such tool, generating important data on the challenges and accounting factors in Ghana, and gaining a basic understanding of the relative impact of these factors. Also, the findings, will not only contribute to the body of academic research by generating new knowledge and establishing practical evidence-base foundation for improving teaching practice and possible student outcomes in this important subject area, thereby enhancing the nation's scientific and technological capacity.

1.8 Significance of the Study

This study holds significant importance for various stakeholders by contributing new knowledge and providing practical tools to address the persistent challenges in atomic and nuclear physics education. The first and most important group who will benefit from the research findings will be senior high school students. By identifying the specific challenges faced by senior high school students and what factors influence them in their learning, the study will aid in the design of better and engaging methods of pedagogy. Better pedagogy is expected to result in improved understanding of concepts in atomic and nuclear physics, improved academic performance in senior high school, and a reduction in the anxiety and difficulty often associated with students in the subject area.

Ultimately, the findings will help create a more supportive learning environment, fostering greater interest in physics and science-related fields.

Secondly, teachers will discover essential information about the root cause their students struggles. This will enhance their instructional methods, design more targeted lesson plans, and prioritise instructional time to address the most impactful factors. Additionally, the psychometrically validated measurement tool developed in this study will be a practical asset for teachers and administrators, allowing them to accurately diagnose student challenges and monitor the effectiveness of their interventions.

Furthermore, the findings of this research will provide a solid empirical basis for curriculum reform and educational policy development. The information provided will be useful to policymakers and curriculum specialists for changing the senior high school science curriculum to better meet the needs of Ghanaian students who may be struggling. The study will also allow for decisions to be made as to the best allocation of resources, teacher professional development, and educational technologies to improve the teaching of atomic and nuclear physics.

This study will be a significant contribution to education in Ghana. It will provide a comprehensive framework with credible evidence to inform further research and encourage comparisons to be made. Furthermore, future researchers interested in following this up will be able to begin with a robust set of results, in order to investigate

additional variables, trial a different pedagogical approach or to repeat the study in an alternative context. This will serve to contribute to the discourse on science education.

1.9 Scope of the Study

This study is delimited to a specific topical, geographical, and population focus to ensure a concentrated and manageable investigation. The topic of the research focuses on the teaching and learning of atomic and nuclear physics at the senior high school level.

It will investigate the challenges students encounter, identify the underlying factors that account for these challenges, determine the psychometric evidence for a tool that measures these factors, and establish the relative impact of the factors. The study does not extend to other branches of physics. The geographical scope is confined to selected senior high schools within the Atwima Nwabiagya Municipality of Ghana. Furthermore, the population scope of the study is restricted to students currently enrolled in the senior high school system within this municipality who study atomic and nuclear physics into detail.

The methodological delimitation of this study is focused on a mixed-methods approach. Additionally, the study employed a mixed-methods exploratory sequential design but emphasised quantitative data collection and analysis through the use of structured questionnaires. Qualitative data were used solely to support the instrument development phase as well as for in-depth interpretive analysis. The study also concentrated on cognitive, instructional, and contextual factors as perceived by students, and did not

directly assess teacher perspectives, classroom observations, or curriculum content in detail.

1.10 Definition of Key Terms

Atomic and Nuclear Physics: This refers to the branch of physics that deals with the structure, properties, and behavior of atoms and nuclei, including topics such as radioactivity, fission, fusion, and the interaction of subatomic particles.

Learning Challenges: These are the cognitive, affective, and contextual difficulties students face in understanding, applying, and solving problems related to atomic and nuclear physics concepts.

Psychometric Assessment: This refers to the systematic process of evaluating the measurement properties (such as validity and reliability) of the instruments used in educational research.

Validity: refers to the degree to which an instrument accurately measures what it purports to measure.

Reliability: Reliability refers to the consistency and stability of measurement results obtained by an instrument over time or across items

Exploratory Factor Analysis (EFA): A statistical technique used to identify the underlying factor structure of a set of observed variables without imposing a predetermined model.

Confirmatory Factor Analysis (CFA): A statistical method used to test whether the data fit a hypothesized measurement model

1.11 Organisation of the Study

The study was categorized into five chapters. The first chapter focused on the background to the study, statement of the problem, purpose of the study, research objectives, research questions, significance of the study, delimitations, limitations, definition of key terms and organization of the study. The second chapter reviewed relevant literature under headings clearly marked. Chapter three indicated the methodology used in the study. It highlighted the research design, population, sample and sampling procedures, research instrument, data collection procedures as well as data analysis procedures. The fourth chapter was devoted to the results and discussions. Finally, the fifth chapter provided summary of the key findings of the study, conclusions and recommendations based on the findings as well as areas for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter provides a comprehensive review of the literature relevant to the study, with an emphasis on the theoretical, conceptual, and empirical background that underpins the investigation of the challenges that students experience in learning atomic and nuclear physics. It begins by examining of three key theoretical perspectives Cognitive Load Theory, Social Cognitive Theory, and Psychometric Theory allowing the researcher to engage with understanding the challenges from a cognitive, social, and measurement dimensions of the study. The chapter then presents the conceptual framework, revealing the connections between: the challenges students face whilst studying atomic and nuclear physics, the contributing factors, and psychometric validation of the research instrument. Following this, the chapter engages with empirical studies to demonstrate: what the challenges are in learning atomic and nuclear physics as well as the underlying factors, along with the instruments available for teaching physics, identifying gaps in the literature. Thereafter the chapter explores the instruments already in use in related studies, highlighting gaps in methodology and justification the necessity for this study. The chapter ends with a summary of the review of literature, emphasising the need for a validated, context-specific tool designed to determine students' challenges and causes of those challenges, within the Ghanaian educational context.

2.1 Theoretical Support of the Study

This research has its foundation based on three main theoretical frameworks, Cognitive Load Theory (CLT), Social Cognitive Theory (SCT) and Psychometric Theory. Each theory provides a certain, but different, complementary lens on the object of the study (i.e., documenting characteristics of the barriers students' have in learning atomic and nuclear physics, exploring the barriers and the circumstances that exacerbate those barriers, documenting the measurement properties of the tools used to detect the barriers and circumstances, and determining the relative importance of barriers and circumstances). This section provides a comprehensive overview of each of the theories, and then explains how each fit with the specific research questions of the study.

2.1.1 Cognitive Load Theory

Cognitive Load Theory (CLT) is a Psychological Instructional Theory developed by John Sweller in the 1980s (Sweller, 2011). Sweller's research on CLT is based on the theory of human cognitive architecture which explains that we can only hold so much new information in working memory (Sweller, 2011). According to Sweller (1994), learning is most effective when instructional designs take into account these cognitive limitations. The theory holds that learners must process information in working memory before it can be encoded into long-term memory, where it becomes part of an organised system of schemas (Paas & van Merriënboer, 2020; Sepp et al., 2019). However, Paas and van Merriënboer (2020) emphasise that if the working memory is overloaded with too much information at once, the learner’s ability to process and retain that information diminishes significantly.

Cognitive Load Theory, as indicated by Sweller (2011), distinguishes among three types of cognitive load: intrinsic load, extraneous load, and germane load. Intrinsic load refers to the inherent difficulty associated with the content itself and is determined by the complexity of the material and the interactivity of its elements (Sweller, 2011). For example, solving a nuclear decay equation that involves multiple steps and conceptual reasoning contributes to high intrinsic load. Extraneous load is the load imposed by the way information is presented or the manner in which a task is structured (Sweller, 2011). Sweller (2011) further argues that poor instructional methods, such as disorganised lectures or unclear problem statements, increase extraneous load unnecessarily. Germane load, in contrast, is the mental effort invested in understanding the material and building new schemas (Sweller, 2011). Therefore, effective instructional designs aim to reduce extraneous load and optimise germane load while managing intrinsic load to match the learner's level of expertise (Sweller, 1994).

In fact, CLT is very important for physics students who are often required to process a lot of information quickly and deal with unfamiliar symbols representations, abstract models, and difficult mathematics ematical problems all at the same time. For example, when learning about atomic and nuclear physics, students need to quickly process a lot of information which included equations, graphs, conceptual representations, and numerical data (Ministry of Education, 2023). Often these representations require the brain to do a lot of different things at the same time, which might include, remembering what they know, using formulas, drawing inferences, and doing the mathematics (Ministry of Education, 2023). Chew and Cerbin (2021) found that when cognitive overload occurs

due to the burden of the knowledge and understanding of the concepts, it can lead to misconceptions, confusion, and poor retention of knowledge. Further, authors Chew and Cerbin (2021) indicated that where students might have surface-level understanding and connections of the concepts to additional ideas, little to no deep connections were made, and there were few connections made between concepts to be able to apply their knowledge to new circumstances.

Cognitive load theory (CLT) represents a broad set of implications for teaching. In order to reduce cognitive load, teachers should consider methods such as breaking information into smaller parts, providing more worked examples, employing visual aids appropriately, or simply increasing the difficulty of the task (Chew & Cerbin, 2021; Paas & van Merriënboer, 2020). Van Nooijen et al. (2024) provide a variety of ways to manage cognitive load, such as scaffolding, reducing redundant (and unnecessary) information, and ensuring that tasks fit what learners are already learning. Chew and Cerbin (2021) note that CLT influences the way in which we structure our content and clarifies why some students may be underachieving in a high-demand subject, in cases where they are sufficiently motivated or have appropriate prior-knowledge. In short, if you want to produce good lessons, find ways to help learners overcome the difficulties of learning in a high-demand subjects - like atomic and nuclear physics - it is essential to understand cognitive load.

2.1.1.1 Alignment of Cognitive Load Theory with the Study

The first research question of this study, which looks to explore the difficulties students face in learning atomic and nuclear physics, is related to cognitive load theory in that the theory provides thorough explanations as to why students might have difficulty with these subjects due to the material itself but perhaps also how it interacts with their cognitive functioning. The nature of the subject involves complex symbolic language, unfamiliar representations, and quantitative problem-solving processes (Ministry of Education, 2023), all of which increase intrinsic cognitive load (Sweller, 2011). Extraneous load is compounded by poor instructional practices, such as poorly organised lessons or presentations that contain too much information (Sweller, 2011).

Therefore, the CLT frame can provide an understanding of the challenges reported by the students, such as conceptual ambiguity, difficult finding solutions to numerical problems, and general academic tiredness and fatigue. In addition, the framework can offer potential solutions to support the development of functional schemas, such as chunking aspects of information, using worked examples, re-designing the instruction, and increasing the complexity of tasks (Chew & Cerbin 2021; Paas & van Merriënboer, 2020; van Nooijen et al., 2024). Thus CLT provides the cognitive and instructional foundation for understanding the learning difficulties in this investigation.

2.1.2 Social Cognitive Theory

Social Cognitive Theory (SCT) has been praised as a model of theoretical development for understanding individual learning and behaviour in social situations and contexts. SCT began from Bandura's (1989) earlier work with observational learning and social

learning theory, which noted that learning does not just occur from direct experience, but with the observation of others and imitation of their behaviours. The key element of SCT is reciprocal determinism, everything we do is an ongoing interaction of personal factors (including cognitive capacities and emotions), social/environmental influences (for example, social context and instructional context), and our behaviour (including what we do and our habits) (Bandura, 2014). Bandura (2014) notes that SCT takes this triadic model of causation further than other theories which argue behaviour is caused solely by internal dispositions or environmental stimuli.

Self-efficacy is one of the most important concepts in SCT. Self-efficacy refers to the confidence one has that they can do something or do a task well (Gale et al., 2021). Bandura (1982) states beliefs about self-efficacy are critical in determining the effort that someone invests in a task, their persistence when faced with challenges, and their ability to stick with it if they experience a failure. Appiah-Twumasi (2024) reported that in a school context, students who are confident in their ability to achieve success in a subject (e.g., physics) take on tasks with confidence, importantly, applying effective study strategies, and persevering through challenge. In contrast, students who lack self-belief may not try hard tasks, have anxiety when face with challenges, or may give up quickly when they struggle. Bandura (1977) states that self-efficacy can be influenced by various factors and mechanisms: examples are past experiences, verbal persuasion, physiological states (e.g., stress), and vicarious learning experiences.

SCT also underscores the significance of modeling, or observational learning (Harinie et al. 2017). Bandura (2014) states that students can learn equally well from themselves, observing their teachers, classmates, and public figures either triumphant or diminished. This notion means students can discern the concept, when a student observes a peer successfully solve a physics problem, the student embraces this notion and believes they can accomplish the same concept. This means that a teacher's actions, such as timely feedback, modeling problem-solving, and encouragement, are also influential. Therefore, learning occurs in a social process and is constantly developing; social interaction and cognitive development are dependent on one another.

The concept of self-regulation, which is the capacity of an individual to plan, monitor, and evaluate their own learning and behaviors, is another key concept in SCT (Bandura, 1991) (Hafnidar et al., 2021). Self-regulated learners are goal-oriented, aware of their strengths and weaknesses, and able to adapt their strategies based on feedback and outcomes (Klimova et al., 2022). As Docktor et al. (2015) point out, self-regulation is particularly important within physics education in which students must solve difficult assignments that require sustained attention, iterations, and conceptual reasoning. In summary, SCT is a useful way to conceptualize how three interrelated factors of a social, cognitive, and motivational level influence students' learning outcomes and experiences within difficult academic disciplines like nuclear and atomic physics.

2.1.2.1 Alignment of Social Cognitive Theory with the Study

The second and fourth research questions of the study is highly aligned with Social Cognitive Theory. The second research question looks at the things that make it hard for students to learn atomic and nuclear physics. SCT offers an appropriate theoretical framework by acknowledging that these challenges stem not only from the complexity of the content but also from students' psychological conditions, motivational level, and social contexts. For instance, a student with low self-efficacy in physics may interpret even simple tasks as difficult, leading to avoidance behaviors, increase anxiety and eventual failure. A classroom environment devoid of encouragement or competent role models may perpetuate detrimental perceptions regarding the study of physics.

The fourth research question, which seeks to determine the relative impact of these factors, also aligns closely with SCT. The theory backs up the idea that things like self-efficacy, peer pressure, teacher feedback, and emotional responses affect how engaged students are and how well they do in school in different ways (Bandura, 2014). SCT's focus on reciprocal determinism (Bandura, 2014) makes it possible to understand how these factors work together and make each other stronger. For instance, a student who does not believe in themselves may avoid practicing physics, which will make them do worse and make them believe in themselves even less. This cyclical interaction is crucial for comprehending why certain students persist in facing difficulties despite multiple instructional interventions. Consequently, SCT offers the theoretical framework for identifying, analysing, and interpreting the personal and contextual factors that affect students' learning experiences in atomic and nuclear physics.

2.1.3 Psychometric Theory

Psychometric Theory, especially Classical Test Theory (CTT), is the basis for creating, testing, and understanding measurement tools in psychology and education research. Classical Test Theory posits that any observed score on a test or questionnaire comprises two components: a true score, reflecting the individual's actual level of the measured trait, and an error score, which addresses random variations and inaccuracies in measurement (Cappelleri et al., 2014; Raykov & Marcoulides, 2016). The primary objective of Classical Test Theory (CTT) is to optimise the ratio of true score variance while minimising error variance, thereby ensuring that the instrument produces reliable and precise outcomes (Frey, 2017; Sijtsma, 2015). This theory is crucial for guaranteeing that the instruments employed in educational research accurately assess what they purport to measure and do so consistently over time.

Reliability is a key idea in psychometric theory (Brown, 2023). It means that measurements are consistent or stable when they are given again or when they are taken from different items on the same instrument (Souza, et al., 2017). In Classical Test Theory (CTT), reliability is predominantly evaluated through statistical indices, including Cronbach's alpha (Taber, 2018), which assesses internal consistency, and test-retest reliability (Harvey, 2021), which measures the stability of responses over time. A high reliability coefficient indicates that the items within a scale assess the same underlying construct consistently (Viladrich et al., 2017). If the instrument is not reliable enough, any conclusions drawn from it are questionable because the results could be due to random error instead of real differences in the trait being measured.

Validity (Brown, 2023) is another important part of psychometric theory. It has to do with how well an instrument measures the construct it was made to measure (Lim, 2024). Validity encompasses various dimensions, including construct validity, content validity, and criterion-related validity (Hughes, 2018). Construct validity entails the demonstration that the instrument accurately represents the theoretical construct upon which it is founded (Ginty, 2020). This is frequently assessed through factor analysis, which investigates the data's underlying structure and the interrelationships among items (Tavakol & Wetzel, 2020). Content validity evaluates the extent to which the items in the instrument encompass all dimensions of the construct, whereas criterion-related validity examines the degree of correlation between the instrument and an external criterion presumed to measure the same concept (Lim, 2024). All types of validity are necessary to prove that the tool is reliable and to make sure that the results are used to make the right decisions and draw the right conclusions.

Psychometric theory is very important in educational studies like this one because it helps to prove that the scales used to measure student perceptions, challenges, and the factors that affect learning are accurate. Before any meaningful analysis can be done, like figuring out how different things affect student problems or comparing groups, the tools must be shown to meet acceptable psychometric standards. This entails a stringent procedure of item formulation, preliminary testing, statistical evaluation, and enhancement. Using psychometric principles makes sure that the data collected is both reliable and easy to understand. This is important for making smart educational decisions and drawing valid conclusions.

2.1.3.1 Alignment of Psychometric Theory with the Study

Psychometric Theory is directly related to the third research question of this study, which aims to determine the reliability and validity of the tool employed to identify factors contributing to students' challenges. This question pertains to methodology and necessitates a theoretical framework that elucidates the evaluation and justification of measurement tools. The research utilises factor analysis to discern the fundamental dimensions of student challenges and employs reliability analysis, including Cronbach's alpha, to guarantee consistent measurement of these dimensions. Classical Test Theory provides a framework for the systematic evaluation and reporting of the psychometric properties of the instrument, including factor structure, internal consistency, and item reliability. This guarantees that the conclusions derived from the data are founded on meticulously designed and statistically sound metrics. Consequently, Psychometric Theory offers the fundamental methodological framework for interpreting and validating the empirical findings of the study.

2.2 Conceptual Framework of the Study

The conceptual framework for this study (refer to Figure 2.1) is based on the relationship between the challenges students face in learning atomic and nuclear physics and the various factors contributing to those challenges. It is also informed by the psychometric processes involved in validating the instrument used to measure these variables and the subsequent analysis of the strength and impact of those factors. The framework integrates both substantive and methodological components to illustrate how the constructs in the study interact and how they align with the stated research questions.

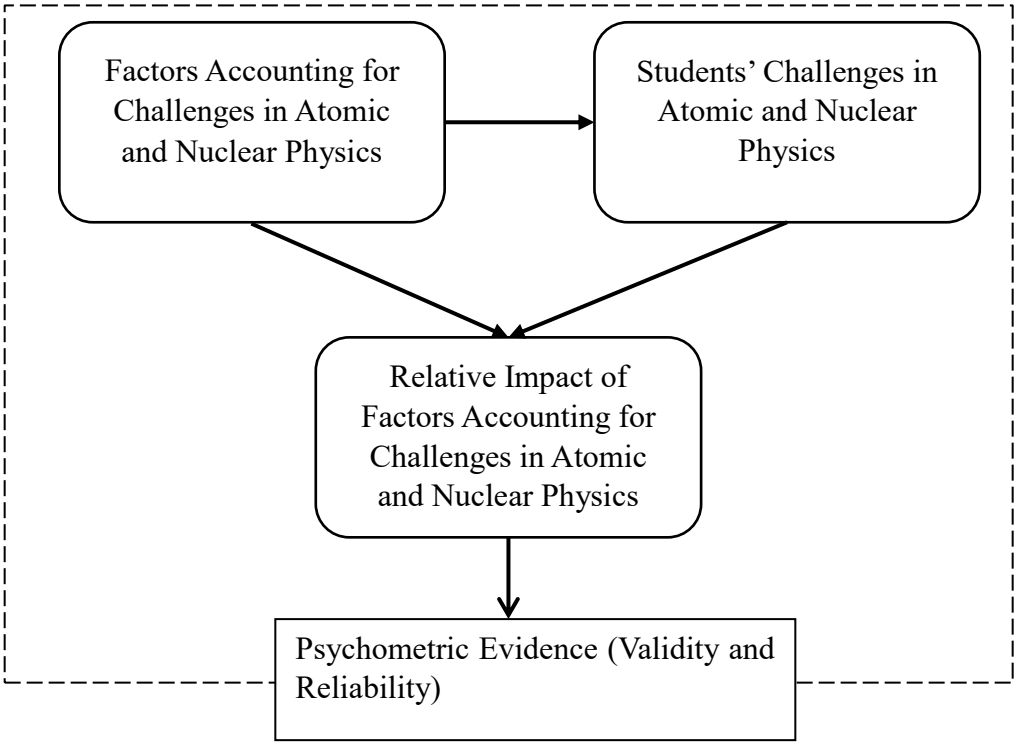

Figure 2.1: Conceptual Framework of the Study

Source: By Researcher

As shown in Figure 2.1, the conceptual framework illustrates the logical flow and interconnectedness of the constructs addressed in the study. It clarifies the research trajectory, from identifying challenges, to explaining them through influencing factors, validating the measurements involved, and analysing their relative impact. It also highlights the theoretical grounding and methodological rigor supporting each phase of the research process.

Beginning with the framework are the factors accounting for students' challenges. These factors represent a range of influences, including cognitive, behavioural, motivational, instructional, and environmental variables, which may hinder students' ability to learn

and understand atomic and nuclear physics. These are derived from the assumptions of social cognitive theory, which acknowledges the role of internal beliefs, classroom dynamics, and social context in shaping student learning behaviour (Bandura, 2014). The framework illustrates these factors as impacting the students' difficulties in mastering atomic and nuclear physics.

Another critical component of the framework is the relative impact of the factors accounting for students' challenges. This construct reflects the analytical goal of the study to determine which of the identified factors contribute most significantly to students' learning difficulties. By modelling the strength of the relationships between each factor and the challenges experienced by students, the study aims to offer actionable insights into which dimensions of the learning environment or student characteristics demand the most attention from educators, curriculum developers, and policymakers. This component aligns with the fourth research question and is shown in the diagram as being influenced by both the explanatory factors and the learning challenges they predict.

The psychometric dimension of the study, which includes all the measured constructs, is what surrounds these conceptual relationships. This part of the framework shows that the study is serious about making sure that the tool used to measure both the student challenges and the contributing factors is valid and reliable. Using classical test theory, psychometric tests are used to check the instrument's measurement integrity through methods like factor analysis and reliability testing. Psychometric evidence does not cause things to happen like the other constructs do; instead, it gives us a solid basis for

confidently understanding the relationships we see. It makes sure that the conclusions drawn from the data are based on measures that are statistically sound.

2.3 Review of Empirical Studies

To understand the problems that students have with atomic and nuclear physics and why they have them, one needs to be familiar with the most recent research. In recent years, numerous studies have examined the conceptual, cognitive, instructional, and contextual barriers to learning modern physics, particularly among senior high school students. This section critically reviews relevant empirical studies from the past decade that align with the core objectives of the present study. The review is structured according to the study's four research questions, with each subsection focusing on how recent findings support, contradict, or extend the understanding of students' difficulties and the psychometric validation of instruments used to measure such challenges.

2.3.1 Challenges Encountered by Senior High School Students in the Teaching and Learning of Atomic and Nuclear Physics

Recent studies have consistently documented the difficulties that senior high school students face when learning atomic and nuclear physics, particularly in three core domains: conceptual understanding, mathematics ematical demands, and problem-solving. Given the limited number of studies specifically focusing on atomic and nuclear physics, this review incorporates related studies in physics education that explore parallel challenges, particularly those involving mathematics ematical reasoning, conceptual understanding, and cognitive barriers.

Morales and Tuzón (2020) found that Spanish secondary students exhibited significant misconceptions about atomic structure, radioactivity, and nuclear processes, often influenced by media portrayals and emotional associations with danger. Similarly, Ejike et al. (2023) reported that South African learners struggled to differentiate between nuclear fission and fusion, and encountered difficulties understanding quantum behaviours such as the wave-particle duality, confirming that the abstract and invisible nature of subatomic processes remains a substantial barrier. Also, Sartika and Humairah (2018) investigated challenges in atomic and nuclear physics education among 36 high school students using diagnostic tests. The study identified a 47.2% misconception rate, with students struggling to understand atomic structure (e.g., electron orbits) and nuclear processes (e.g., radiation and half-life). Furthermore, Ewim et al. (2023) examined nuclear energy knowledge among 100 South African high school students. The study found low awareness and prevalent misconceptions, such as 10–20% of students believing coal powers nuclear plants. Only 6% of public-school students correctly distinguished fission from fusion.

Mathematics ematical requirements constitute another major domain of challenge. Bray and Williams (2018) investigated challenges in physics education at Rhodes University via interviews and surveys. Difficulties encompassed inadequate mathematics ematical proficiency, misconceptions in abstract domains such as atomic and nuclear physics, fear of failure, and unproductive study habits. In a study, Reddy and Panacharoensawad (2017) surveyed 303 high school students in Malaysia to find out what made it hard for them to solve physics problems. The study identified considerable challenges, such as

difficulties in recalling equations (57%), inadequate classroom practice (55.1%), insufficient conceptual understanding (50.8%), and deficient mathematics ematical skills (50.8%).

Tong et al. (2025) showed that students who were not good at mathematics operations like algebraic manipulation, scientific notation, and graph interpretation had a harder time solving physics problems. Mutambo et al. (2018) also found that students who had already learned mathematics still had trouble with mathematics representations, especially when they had to use functions and read vector diagrams in physics. Brahmia et al. (2016) noted that even university students encounter difficulties in mathematising physics problems owing to inadequate symbolic reasoning abilities and a deficient comprehension of quantitative relationships, underscoring the widespread challenges in mathematics ematical aspects of physics education.

Research indicates that students struggle to apply theoretical knowledge to practical situations in the realm of problem-solving. Sartika and Humairah (2018), employing Polya's framework, noted that Indonesian students faced difficulties in problem comprehension, strategic planning, and solution evaluation while addressing nuclear physics questions. Gousopoulos (2023) also stressed that students often do not use structured reasoning strategies and instead rely on surface-level recall, which makes it harder to solve problems. Moreover, a synthesis by Park (2020) revealed that novice learners often utilize formulas without engaging in conceptual analysis or interpretation, reflecting prevalent procedural deficiencies in physics education.

2.3.2 Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics

Empirical studies in the past decade have identified key factors that contribute to students' difficulties in learning physics. This section examines the factors contributing to challenges faced by senior high school students in learning atomic and nuclear physics. However, it is important to note that studies directly related to atomic and nuclear physics are not widely available; therefore, this review considers parallel studies focusing on physics and science education in general to provide a comprehensive understanding of the underlying factors.

Cheung (2017) examined the factors affecting junior secondary school students' interest in science in Hong Kong, pinpointing situational influences, personal interest, and science self-concept. Quantitative analysis indicated that self-concept is the most significant predictor of interest. This study indicates that a diminished science self-concept and an absence of engaging strategies likely exacerbate difficulties in abstract physics subjects, advocating for inquiry-based activities and positive reinforcement. Musah et al. (2022), in his study of Ghanaian secondary schools, found that the abstract nature of atomic and nuclear concepts like radioactive decay, electron transitions, and quantum behaviors caused confusion and low engagement.

This corresponds with previous research by Çermik (2020), which investigated physics learning difficulties among high school students in Turkey, revealing that 94.15% encountered challenges. Four primary factors were identified: content-related (abstract

concepts, intricate formulas), individual-related (adverse attitudes), teacher-related (insufficient methodologies), and environmental-related (absence of laboratories). Students had trouble with abstract ideas and memorising formulas, which was made worse by not being able to do experiments, which is why hands-on teaching is needed. Moreover, Tindan and Arthur (2024) investigated the challenges faced by high school students in learning physics, highlighting the significance of course content and demographic variables. The main problem with the course content was that it was too abstract and the textbooks weren't interesting enough. This was different for each grade level. Students in ninth and eleventh grades also felt more accountable for their challenges.

These results corroborated previous findings indicating that abstract physics content impedes comprehension, particularly for specific grade levels. Coffie et al. (2020) investigated the challenges associated with teaching and learning physics in Ghanaian senior high schools. Teachers said that the problems were with the students (like not being good at mathematics), while students said that the problems were with the teachers (like not being good at teaching). Both groups agreed that resources were limited, especially when it came to laboratory. The reliance on theoretical instruction for abstract subjects such as atomic and nuclear physics intensified challenges, resulting in suggestions for teacher professional development and governmental investment in scientific resources.

Wangchuk et al. (2023) also looked into the problems that students in grades 9–12 at a Bhutanese higher secondary school had. The majority of students (59.6%) perceived physics as challenging, attributing their difficulties to student-related factors (motivation, mathematics ematical proficiency), curriculum-related issues (insufficient real-life application), and subject-related characteristics (abstract, cumulative nature). Problems got worse because of things like teachers who taught in a boring way. The study suggests integrating local contexts and strengthening mathematics ematical foundations for more relevant learning. Saka et al. (2024) examined the physics problem-solving perceptions of Turkish pre-service teachers. Some of the problems were not being good at mathematics, not being able to think visually, and not being able to connect data to principles. National examination that required students to memorise facts made it harder for them to think critically, especially about abstract topics like atomic and nuclear physics. The study says that combining knowledge and using interactive teaching methods can help people solve problems more effectively.

Dahal (2022) examined the perceptions of students and teachers regarding effective physics instruction in Nepal. Some important things about students were their weak foundations and their fear of physics. Problems with teachers included ineffective methods and a lack of real-world use. Environmental factors, such as a lack of materials, were also brought up. The research validated the abstract characteristics of physics and the necessity for practical, stimulating methodologies in subjects such as atomic and nuclear physics. In summary, these studies collectively underscore various factors that impede physics education, particularly regarding abstract subjects like atomic and nuclear

physics. These challenges arise from the subjects' abstract and theoretical characteristics, exacerbated by ineffective teaching methods, diminished student confidence, inadequate mathematics ematical preparation, restricted practical resources, and psychological impediments. The persistent finding across studies is the adverse dependence on theoretical instruction for subjects necessitating visualisation and experimentation.

2.3.2 Psychometric Evidence Supporting the Reliability and Validity

This section discusses various types of validity and reliability, and reviews methodologies for their establishment. The section concludes by critically analysing existing instruments and highlighting the justification for psychometric evaluation in the current study.

2.3.2.1 Foundations of Psychometric Properties: Reliability and Validity

The creation and use of good assessment tools in educational research, especially in difficult areas like physics, depend a lot on their psychometric properties. Psychometrics has changed a lot since it started in the early 1900s. It has gone from just measuring psychological traits to carefully checking the quality of the tests themselves. This evolution highlights the critical necessity of guaranteeing that any instrument employed to evaluate student comprehension, discern misconceptions, or assess learning challenges is both reliable and precise. Without strong psychometric evidence, the results from these tools would not be trustworthy, which could make future teaching methods or changes to the curriculum less effective.

Reliability and validity are the two main ideas behind psychometrics (Cohen et al., 2018). Bahariniya et al. (2021) say that reliability is the consistency of a measurement, which means that an instrument should give the same results every time it is used. It pertains to the reproducibility of data (Biasutti & Frate, 2017), indicating that if an assessment is conducted repeatedly with the same individuals in analogous conditions, it should produce consistent results. For example, if arrows shot at a target always land close to each other, even if they do not hit the bullseye, the shooting is accurate. This consistency is essential to guarantee that any observed changes or disparities in student performance result from authentic learning or legitimate challenges, rather than measurement error.

Validity, on the other hand, is the degree to which a tool measures what it says it does. This makes sure that the assessment really looks into its goal or tests the underlying hypothesis (Singh, 2017). This means that reliability is about consistency, while validity is about correctness and suitability. Cohen et al. (2018) assert that an instrument may consistently yield inaccurate results, indicating that it can be reliable yet not valid. If the arrows always hit the same spot far from the bullseye, for instance, the shooting is reliable but not accurate or valid for hitting the target. This distinction is essential; a consistent yet invalid measure yields misleading information, whereas a valid measure, despite some variability, provides significant insights into the intended construct.

Thus, it is essential to establish both reliability and validity for any research undertaking. The lack of either property diminishes the reliability of the collected data and, subsequently, the inferences derived from the research (Cohen et al., 2018; Ishtiaq &

Ishtiaq, 2021). For example, an unreliable tool cannot give you consistent data, which makes it hard to tell if changes are real or if traits are stable. An invalid instrument, even if consistent, measures something other than what was intended, resulting in incorrect assessments of student abilities or learning difficulties. Consequently, stringent psychometric evaluation is not only a technical necessity but also a fundamental prerequisite for safeguarding the scientific validity and practical efficacy of educational assessments.

In short, a full psychometric evaluation that includes both reliability and validity is necessary to make sure that assessment tools give useful and correct data to answer research questions. This basic knowledge helps you choose, change, or make new assessment tools that are right for the job and can give you reliable information about what students are having trouble with and what factors are affecting them in complex subjects like atomic and nuclear physics.

2.3.2.1.1 Types of Validity Evidence

Establishing the validity of a research instrument is a comprehensive process that typically involves gathering multiple types of evidence. These various forms of evidence contribute to an overall argument for the meaningfulness and appropriateness of the scores derived from the instrument. These forms of validity evidence include content validity, construct validity, criterion-related validity (which encompasses concurrent and predictive validity), and face validity.

Content Validity: Content validity evidence looks at how well the questions or items on a test or questionnaire sample the content domain or construct being measured (Ishtiaq & Ishtiaq, 2021). When studying atomic and nuclear physics, content validity means making sure that the questions cover all the important sub-topics (like quantum numbers, radioactive decay, nuclear reactions, and wave-particle duality) and types of problems (like conceptual, mathematics ematical, and problem-solving) that seniors high school students might have to deal with. It is a type of validity that does not use statistics and is mostly based on expert opinion.

A panel of subject matter experts, such as experienced physics teachers, curriculum developers, and physics education researchers, usually reviews the instrument's items to see if they are relevant, clear, and cover the full range and depth of the domain as defined by the study's goals and the curriculum (Obilor & Miwari, 2022). For example, if a questionnaire's goal is to find out what problems students have with quantum physics because it is so abstract, the expert panel would look at whether the questions are good enough to show how hard students find things like wave functions, probability distributions, or the uncertainty principle. Their agreement as a group is strong proof of content validity, which means that the tool accurately represents the construct it is supposed to measure.

Obilor and Miwari (2022) say that this kind of validity is usually achieved through expert review, in which a group of experts in the subject matter carefully checks each item for its relevance, clarity, and representation of the content domain. The experts check to see

if the items are a good representation of the skills and content that the instrument is meant to measure. This process often involves figuring out V-Aiken's coefficients for each item or for the whole instrument (Anindyarini & Rosnawati, 2019; De-Moya-Romero et al., 2025; Rismawati, 2023). A V-Aiken's coefficient of 0.75 or higher is generally thought to show that the content is valid (Anindyarini & Rosnawati, 2019). This means that experts agree that the instrument's items are appropriate and comprehensive.

Construct Validity: Construct validity is arguably the most fundamental and complex type of validity evidence, focusing on the extent to which a test measures the theoretical construct it is intended to measure (Anindyarini & Rosnawati, 2019). A "construct", according to Cohen et al. (2018), is an unobservable concept or idea, such as "conceptual understanding of atomic structure," "scientific self-efficacy," or "learning motivation," which is inferred from observable behaviours or responses. Therefore, establishing construct validity involves accumulating evidence that supports the theoretical relationships between the construct and other variables. This often involves both convergent validity and discriminant validity (Sujati et al., 2020).

Convergent Validity: Convergent validity evidence is gathered when scores on the instrument correlate highly with scores on other measures that are theoretically expected to be related to the same construct (Cheung et al., 2024). This means that different methods or measures of the same construct should yield similar results. For example, a newly developed questionnaire designed to assess "conceptual understanding of atomic

structure" should demonstrate a strong positive correlation with students' scores on a well-established and validated atomic physics concept inventory.

The expectation is that if both instruments are genuinely measuring the same underlying construct, their scores should converge (Cheung et al., 2024). According to Cheung et al. (2024), high positive correlations, often above 0.50 or 0.60, are typically sought to indicate adequate convergent validity, suggesting that the new instrument captures the intended construct effectively alongside existing measures. This is often assessed by examining the average variance extracted (AVE) from a Confirmatory Factor Analysis (CFA), where an AVE value of ≥ 0.50 indicates that a construct explains more than half of the variance of its indicators, implying good convergent validity (Shrestha, 2021).

Discriminant Validity: Discriminant validity (or divergent validity) evidence is acquired when instrument scores exhibit minimal or no correlation with measures of constructs that are theoretically unrelated (Cheung et al., 2024). This shows that the instrument is different from other measures and is not just measuring a different but related construct. For example, an instrument created to assess senior high school students' "difficulties in understanding nuclear decay" should exhibit a low or negligible correlation with a measure of their "general anxiety levels," as these two constructs are theoretically separate. If a strong correlation were found, it would mean that the tool might be picking up on general anxiety instead of specific problems with nuclear physics.

The Heterotrait-Monotrait Ratio of Correlations (HTMT) is a more stringent criterion for evaluating discriminant validity, especially in the realm of structural equation modelling (SEM) and variance-based SEM techniques such as Partial Least Squares (PLS-SEM) (Ab Hamid et al., 2017; Roemer et al., 2021). To get the HTMT ratio, you divide the average of the correlations between indicators measuring different constructs (heterotrait-heteromethod correlations) by the geometric mean of the average correlations among indicators measuring the same construct (monotrait-heteromethod correlations). It basically figures out how closely two constructs are related (Roemer et al., 2021).

A high HTMT value indicates a deficiency in discriminant validity. There have been different suggestions for thresholds, but an HTMT value of ≤ 0.85 (Ab Hamid et al., 2017) is a widely used standard for showing that two constructs are different. Ab Hamid et al. (2017) contend that for constructs that are conceptually analogous, a more stringent threshold of ≤ 0.90 may be applicable. If the HTMT value is higher than these limits, it means that the two constructs are not different enough from each other, which could mean that there is a problem with the measurement model.

Criterion-Related Validity: Criterion-related validity evidence evaluates the degree to which an instrument's scores correlate with an external criterion, defined as an independent measure of the same or a related construct. Concurrent validity and predictive validity are the two main types of criterion-related validity.

Concurrent Validity: Concurrent validity is demonstrated when the instrument's scores exhibit a strong correlation with scores from a recognised, established criterion measure administered simultaneously (Bahariniya et al., 2021). Bahariniya et al. (2021) assert that this form of validity is especially advantageous when creating a novel, potentially more efficient or accessible instrument to supplant an existing, albeit possibly more cumbersome, measure. For instance, if a new, shorter diagnostic test for atomic and nuclear physics challenges is created, its scores should exhibit a strong correlation with students' current physics course grades or their performance on a concurrent comprehensive, standardised physics examination. To show strong concurrent validity, researchers often look for high positive correlations, usually above 0.70. This means that the new tool gives information that is consistent and comparable to information from other trusted measures (Lin & Yao, 2024).

Predictive Validity: Predictive validity, as its name implies, refers to the degree to which an instrument's scores can reliably forecast future performance or outcomes on a pertinent criterion (Bahariniya et al., 2021). This kind of validity is very important for tools that are used to choose, place, or predict (Lin & Yao, 2024). For example, an assessment of senior high school students' fundamental physics knowledge or their recognised difficulties in particular physics subjects could be utilised to forecast their future success or challenges in a more advanced university-level atomic and nuclear physics course. The relationship between the instrument scores and future results (like course grades or performance on a later test) shows that the instrument is valid for making predictions. Higher correlation coefficients, which usually fall between 0.30 and 0.60 depending on how hard the

prediction is (Lim, 2024), show strong predictive power, demonstrating the instrument's utility in forecasting future academic performance.

Face Validity: Face validity is the least rigorous type of validity evidence and is not a psychometric validity in the strictest sense. However, it is often seen as a useful part of instrument development. It means how much an instrument seems to measure what it is supposed to measure at first glance (Lim, 2024). In simpler terms, it is about whether a non-expert or the people taking the test can tell that the instrument is measuring what it was meant to measure. For example, a questionnaire designed to assess challenges in atomic and nuclear physics would have good face validity if its questions explicitly use terms like "atomic structure," "radioactivity," or "quantum mechanics." While not established through statistical analysis or expert review in the same way as content or construct validity, face validity can influence participant motivation and engagement. If an instrument does not appear relevant or appropriate to the respondents, they might not take it seriously, potentially compromising the quality of the data. Therefore, while not a substitute for more rigorous validity evidence, ensuring an instrument has reasonable face validity can be beneficial for practical administration.

2.3.2.1.2 Methodologies for Establishing Validity

Establishing validity is a multi-faceted process employing various methodologies, often in combination, to build a compelling argument for the inferences drawn from test scores. For content validity, the primary methodology is expert judgment and review. This involves assembling a panel of subject matter experts who independently rate the

relevance, clarity, and representativeness of each item in relation to the defined content domain.

For construct validity, a range of statistical techniques are employed. This includes exploratory factor analysis (EFA) and confirmatory factor analysis (CFA).

Exploratory Factor Analysis (EFA): Exploratory Factor Analysis (EFA) is a statistical technique used to identify the underlying dimensions or "factors" within a set of observed variables (items) when no strong a priori theoretical structure is assumed (Watkins, 2018). Thus, in instrument development, EFA helps researchers explore how items group together and which latent constructs they represent (Goretzko et al., 2021). For an instrument designed to assess challenges in atomic and nuclear physics, EFA could reveal if student difficulties naturally cluster into categories such as "conceptual misunderstandings," "mathematics ematical application issues," or "abstract reasoning difficulties."

It is important to check the data's suitability before doing an EFA (Goretzko et al., 2021). The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy is a common tool that gives values between 0 and 1. For factor analysis, a KMO value of 0.60 or higher is usually acceptable. This means that the variance in the items is mostly common and not unique. Values over 0.70 are good, and values over 0.80 are great (Watson, 2017). The Bartlett's Test of Sphericity is another important test that checks the null hypothesis that the correlation matrix is an identity matrix, which means that the variables are not related.

If Bartlett's Test gives a statistically significant result ($p < 0.05$), it means that the data are good for factor analysis because there are strong relationships between the variables (Goretzko et al., 2021; Watson, 2017). After EFA, the communalities (the amount of variance in an item that can be explained by the common factors) should be higher than 0.40 or 0.50 for each item. The factor loadings (the correlation between an item and a factor) should also be higher than 0.32 or 0.40 (Hair et al., 2021) to show that there is a meaningful link between the item and the factor.

Confirmatory Factor Analysis (CFA): Confirmatory Factor Analysis (CFA) is a more advanced statistical method for testing a hypothesised factor structure that is based on existing theory or previous EFA findings. CFA is different from EFA in that the researcher must specify the number of factors and which observed variables (items) load onto which factors before the analysis begins (Hair et al., 2021). For instance, if an existing theoretical framework suggests that students' challenges in atomic and nuclear physics are composed of three distinct but related factors (e.g., quantum concept difficulty, nuclear reaction difficulty, and historical context misunderstanding), CFA would be used to statistically test whether the collected data fit this hypothesised model.
After specifying the model, CFA involves assessing the model fit indices to determine how well the hypothesised model fits the observed data. Common model fit indices and their generally accepted thresholds include:

The chi-square ($\chi 2$) statistic is the most basic fit index. It tests the null hypothesis that the model fits the data perfectly (Hair et al., 2021). A non-significant p-value ($p > 0.05$)

indicates an adequate fit. However, Hair et al. (2021) emphasise that $\chi 2$ is extremely sensitive to sample size, frequently yielding significant results with large samples even for trivial discrepancies. Because of this, people usually use other fit indices. The ratio of chi-square to degrees of freedom ($\chi 2/df$) is also used, and values between 1.0 and 3.0 (or up to 5.0) show that the fit is good (Goretzko et al., 2024).

The Root Mean Square Error of Approximation (RMSEA) measures how well the model fits the population covariance matrix. Lower values mean a better fit. Research (Goretzko et al., 2024; Hair et al., 2021; Hu & Bentler, 1999) indicates that RMSEA ≤ 0.06 signifies a good fit, while RMSEA ≤ 0.08 denotes an acceptable fit. Values higher than 0.10, on the other hand, show that the fit is bad. You should also look at the 90% confidence interval for RMSEA. The upper limit should be less than 0.08 (Hair et al., 2021).

Standardised Root Mean Square Residual (SRMR): This is a way to find the average difference between the predicted and observed correlations. Values of SRMR that are less than or equal to 0.08 show a good fit (Goretzko et al., 2024; Hair et al., 2021; Hu & Bentler, 1999). Lower values are better because they mean that the model fits the data better.

Comparative Fit Index (CFI): This index looks at how well the hypothesised model fits compared to a baseline model, which is usually a null model where all the variables are not correlated. Better fit is shown by values that are closer to 1.0. A CFI of 0.90 or higher

is usually seen as acceptable, while a CFI of 0.95 or higher means a good fit (Goretzko et al., 2024; Hair et al., 2021; Hu & Bentler, 1999).

Tucker-Lewis Index (TLI) / Non-Normed Fit Index (NNFI): TLI is like CFI in that it compares the hypothesised model to a null model, but it punishes models that are too complex. Most people agree that values of 0.90 or higher are acceptable, and values of 0.95 or higher show a good fit (Goretzko et al., 2024; Hair et al., 2021; Hu & Bentler, 1999).

Correlation coefficients are principally employed for criterion-related validity. To determine concurrent validity, the Pearson product-moment correlation coefficient (r) is computed between the scores obtained from the new instrument and those from a concurrent criterion measure. A strong positive correlation (e.g., $r > 0.70$) would indicate robust concurrent validity (Mohajan, 2017). Regression analysis can be used to find out how well scores on the instrument predict future performance on the criterion (Cohen et al., 2018). Cohen et al. (2018) assert that the coefficient of determination (R2) signifies the percentage of variance in the criterion that can be elucidated by the instrument's scores.

2.3.2.1.3 Methodologies for Establishing Reliability

Establishing the reliability of an instrument also involves several well-established methodologies, each assessing different aspects of consistency. Internal consistency reliability is the most commonly reported type in educational research, assessing the

consistency of results across items within the same test or questionnaire. The most widely used statistic for internal consistency is Cronbach's alpha (α), particularly for scales with multiple Likert-type items. Cronbach's Alpha is calculated as:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma_{Y_i}^2}{\sigma_X^2}\right)$$

where k is the number of items, $\sigma_{Y_i}^2$ is the variance of item i, and σ_X^2 is the variance of the total score. Taber (2018) indicates that a higher alpha value (typically 0.70 or higher for research purposes, 0.80 for high-stakes assessments) indicates greater internal consistency, suggesting that the items are measuring the same underlying construct. For dichotomous items (e.g., true/false, correct/incorrect), the Kuder-Richardson Formula 20 (KR-20) is used, which is a special case of Cronbach's Alpha (Ntumi et al., 2023).

Cronbach's Alpha is a common tool, but it is based on a number of assumptions, one of which is tau-equivalence (all items contribute equally to the true score variance) (Hayes & Coutts, 2020). Consequently, when these assumptions are breached, Alpha may understate the actual reliability. Consequently, Omega reliability (ω), notably McDonald's Omega, has become increasingly recognised as a superior and precise metric for assessing internal consistency, particularly within the realms of factor analysis and structural equation modeling.

Omega reliability calculates the percentage of variance in the overall score that can be ascribed to the common factors (i.e., the true score variance), factoring in the item-specific factor loadings and unique variances (Hayes & Coutts, 2020). When items measure only one underlying construct (unidimensionality) or when a multi-dimensional

structure is present (Watkins, 2017) and assessed through CFA (Viladrich et al., 2017), it is seen as a better estimate of reliability. Hayes and Coutts (2020) contend that Omega is especially advantageous as it does not presuppose tau-equivalence, thereby offering a more precise assessment of composite reliability when item loadings across their respective factors are unequal.

There are different kinds of Omega, like Omega total and Omega hierarchical (Watkins, 2017), but McDonald's Omega is the most common. An Omega value of 0.70 or higher is usually acceptable, and a value of 0.80 or higher means that the test is reliable (Hayes & Coutts, 2020). Due to its theoretical benefits and better fit with common measurement models (e.g., those assessed via CFA) (Watkins, 2017), Omega reliability is becoming more and more recommended as a complementary or even preferred reliability estimate to Cronbach's Alpha, giving a more detailed picture of scale consistency. Another way to check reliability is to see how stable scores are over time by doing a test-retest. This entails administering the identical instrument to the same cohort on two distinct occasions, with a suitable interval (e.g., two to four weeks) to mitigate memory effects while ensuring sufficient duration for genuine changes to manifest. After that, the Pearson correlation coefficient is found between the two sets of scores. A high positive correlation coefficient (e.g., $r > 0.80$) shows that the test-retest reliability is good, which means that the instrument gives the same scores over time.

Inter-rater reliability is essential when the evaluation entails subjective judgment or observation by several raters (e.g., coding open-ended responses, monitoring classroom

behavior). This approach evaluates the reliability of evaluations or ratings provided by two or more autonomous observers. Cohen's Kappa (κ) for categorical data and Intraclass Correlation Coefficient (ICC) for continuous data are two common ways to measure inter-rater reliability. Cohen's Kappa corrects for chance agreement. A high inter-rater reliability means that different raters would mostly agree on the scores or categories, which lowers the measurement error caused by differences between raters.

Lastly, parallel-forms reliability (or alternate-forms reliability) looks at how consistent two different but equal versions of the same test are. Two versions of the instrument, intended to assess the same construct but comprising different item sets, are given to the same group of individuals. The relationship between the two scores shows that the forms are reliable. This method is especially helpful when testing needs to be done multiple times and memory or practice effects are a problem. It reduces the effect of being familiar with certain items.

In conclusion, the careful use of these methods to check for validity and reliability is not just a technical task; it is a necessary part of ethical and thorough research. Researchers can confidently say that their tools are giving them accurate and consistent data if they show strong psychometric evidence. This makes their findings about students' problems in atomic and nuclear physics more credible and applicable to other situations. This strict method is necessary for making useful contributions to the field of physics education.

2.3.2.2 Review of Existing Instruments and Their Psychometric Properties

This section provides a critical overview of existing measurement instruments relevant to physics education and related fields, particularly those designed to assess conceptual understanding, metacognition, attitudes, or psychological factors influencing engagement in educational contexts. While no directly comparable instrument specifically targeting the challenges and contributing factors in atomic and nuclear physics for senior high school students with established psychometric properties appears to exist in the extant literature, a systematic review of related instruments is crucial. This review serves to: (1) highlight the current state of measurement in physics education, (2) identify methodological best practices in instrument development and validation, and (3) underscore the unique contribution and necessity of the instrument developed in the present study.

2.3.2.2.1 Instruments Assessing Conceptual Understanding and Metacognition in Physics

Researchers have created tools to measure conceptual understanding and metacognitive awareness in physics education, yielding significant insights into student cognition. For example, Asriadi and Sanam (2025) assessed the psychometric quality of a 14-item diagnostic test instrument on physics wave material for 11^{th}-grade students in Bandung City, West Java, Indonesia. Seven experts used Aiken's V to check the content validity, and the average score of 0.849 was "very valid." A KMO value of 0.946 and a significant Bartlett's Test ($p = 0.000$) showed that construct validity was strong. All items had MSA values above 0.912. Confirmatory Factor Analysis (CFA) demonstrated a satisfactory

model fit (CFI = 0.948, TLI = 0.935, RMSEA = 0.072, SRMR = 0.043), notwithstanding a low Chi-square p-value. The latent variable "Wave" exhibited a significant effect (estimate = 0.232, p = 0). The reliability was excellent, with a McDonald's Omega of 0.931, a Cronbach's Alpha of 0.926, and an average inter-item correlation of 0.470. This study successfully created a psychometrically sound diagnostic tool for physics wave material, providing a dependable means to detect student misunderstandings and guide instructional approaches.

Another pertinent instrument is the Heat and Temperature Metacognition Awareness Inventory (HeTMAI), created by Sukarelawan et al. (2021) in Yogyakarta, Indonesia, to validate the HeTMAI among 167 public senior high school students. Using Confirmatory Factor Analysis (CFA) with a Maximum Likelihood approach, they found that the 26-item HeTMAI, which was based on the Physics Metacognition Inventory, had a strong six-factor structure. The overall model fit was good, with $\chi 2/df=2.36$, CFI=0.97, TLI=0.97, and SRMR=0.06. However, RMSEA was 0.09. Standardised factor loadings (0.56-0.92), construct reliability (0.75-0.94), and average variance extracted (0.52-0.80) all showed that convergent validity was supported. All of these values were above the recommended thresholds. Discriminant validity was validated, evidenced by AVE values exceeding squared inter-construct correlations. The instrument exhibited substantial reliability, evidenced by an overall Cronbach’s alpha of 0.96, with factor-specific alphas varying from 0.78 to 0.94. This study effectively validated HeTMAI as a dependable and valid instrument for evaluating metacognitive awareness in the domain of heat and

temperature physics, offering precise data for educators to formulate effective pedagogical strategies and assess curricula in Indonesia.

In Kazakhstan, Japashov et al. (2024) examined the structure of university undergraduate students' understanding of the force concept through a three-tier Force Concept Inventory (FCI) survey. The instrument exhibited substantial reliability, as evidenced by Cronbach's alpha values of 0.85 for first-tier items and 0.91 for both-tier and all-tier items, reflecting robust internal consistency. Evidence of validity included high content validity, which was backed up by expert review and the translation and validation for the people of Kazakhstan. Principal Component Analysis (PCA) demonstrated construct validity, evidenced by a significant Bartlett's test ($\chi 2 = 33307.41$, $p < 0.001$) and a KMO of 0.701, indicating a single dominant latent trait. A statistically significant correlation ($r = 0.186$, $p = 0.012$) between correct answers on both tiers and confidence scores further validated construct validity. A moderate, statistically significant correlation ($r = 0.34$, $p < 0.001$) between students' end-term physics marks and their all-tiers scores further substantiated predictive validity. This study effectively created a psychometrically sound instrument for evaluating conceptual comprehension and misconceptions in Mechanics within the Kazakhstani framework.

2.3.2.2.2 Instruments Assessing Affective and Psychological Factors in Science and STEM Education

In addition to cognitive dimensions, numerous studies have concentrated on creating tools to evaluate affective and psychological factors that impact engagement and learning

in science and STEM disciplines. Kaltakci-Gurel (2021) concentrated on the Turkish adaptation and psychometric assessment of the 42-item Colorado Learning Attitudes about Science Survey (CLASS) in Physics, employing a sample of 1,220 freshman university students. Following expert evaluations and student interviews to assess content and face validity, Exploratory Factor Analysis (EFA) was conducted. This process, involving the iterative removal of items, resulted in a 20-item, three-factor model that accounted for 39.61% of the total variance. A KMO of 0.888 and a significant Bartlett's Test (p=0.00) backed up this EFA. The Confirmatory Factor Analysis (CFA) on this 20-item model produced satisfactory fit statistics (e.g., $\chi 2/df=2.410$, GFI=0.940, CFI=0.901, RMSEA=0.048, SRMR=0.045), although NFI and NNFI did not demonstrate adequate fit. The overall reliability of Cronbach's alpha was 0.853 (EFA data) and 0.835 (CFA data). The alphas for each factor ranged from 0.644 to 0.778. This study created a shorter, valid, and reliable Turkish version of the CLASS to fix the original instrument's problems with being one-dimensional.

Summers and Abd-El-Khalick (2018) created and tested the 30-item Behaviours, Related Attitudes, and Intentions towards Science (BRAINS) survey, which is based on the Theories of Reasoned Action and Planned Behaviour (TRAPB). It is used to measure how students in grades 5 through 10 feel about science. The instrument was given to a representative sample of 1,291 Illinois students and went through a strict Confirmatory Factor Analysis (CFA) and improvement process. The final 30-item instrument, which had five different factors, fit the data very well statistically, with a Root Mean Square Error of Approximation (RMSEA) of 0.04 and a Comparative Fit Index (CFI) of 0.95.

The scale reliabilities for the five factors ranged from 0.70 to 0.91, which shows that the factors are very consistent with each other. This study offers a robust, psychometrically valid tool for evaluating general science attitudes, establishing a solid framework for instrument development in science education.

Badeo and Duque (2023) sought to reassess the psychometric properties of the 42-item Colorado Learning Attitudes about Science Survey (CLASS) for physics, employing a sample of 227 senior high school students from Metro Manila and Cavite, Philippines. Following preliminary data cleansing and inter-item correlations, Exploratory Factor Analysis (EFA) was conducted, resulting in a refined 29-item instrument. This EFA, which had a "great" KMO score of 0.833 and a significant Bartlett's Test ($\chi 2=2011.69$, $\rho<0.05$), found four factors that explained 54.90% of the total variance. The instrument exhibited satisfactory overall Cronbach's alpha reliability of 0.745, with individual factor reliabilities varying from 0.712 to 0.772, thereby affirming its validity for assessing student attitudes in physics. The updated CLASS tool is a valid and reliable way to find out how senior high school students feel about physics.

Appiah-Twumasi et al. (2022) created and validated the Physics Learning Self-Efficacy (PLSE) questionnaire to evaluate self-efficacy beliefs among 290 Senior High School Physics students in Ghana. Using Principal Component Analysis (PCA), the study identified four factors: Physics Practical (5 items), Everyday Application (4 items), High-Order Thinking Skills (4 items), and Physics Content (4 items), with loadings ranging from 0.588 to 0.889, collectively accounting for 68.995% of the variance. The overall

Cronbach's alpha was 0.796, and the corrected item-total correlations ranged from 0.571 to 0.752. The Average Variance Extracted (AVE) values ranged from 0.540 to 0.718 and the Composite Reliability (CR) values ranged from 0.823 to 0.927, which showed that convergent validity was supported. Six experts confirmed content validity, resulting in an accepted CVR of 0.990. The sample was considered sufficient, as indicated by a KMO of 0.791 and a significant Bartlett's Test ($\chi 2=910.005$, $p<0.05$). This study successfully created a psychometrically robust instrument for assessing physics learning self-efficacy within a particular cultural context, offering a significant resource for researchers and educators in Ghana.

Setiawan et al. (2024) developed an instrument to assess the teaching process in higher education, utilising a sample of 1200 students from eight faculties at Universitas Negeri Yogyakarta, Indonesia. Six experts used the V-Aiken method to check the content validity, and the average score was 0.752, which is a high score. Confirmatory Factor Analysis (CFA) showed that construct validity was good, with 14 out of 15 items having good loading factors (>0.3). The component loadings for Planning, Process, and Evaluation were 0.957, 0.970, and 0.932, respectively. The instrument showed high reliability, with an overall Cronbach's alpha of 0.865 and composite reliability scores above 0.65 for all parts (e.g., Evaluation = 0.914, Planning = 0.897). The SRMR values of 0.095 (saturated) and 0.096 (estimated) showed that the model fit well with the developed model. This study successfully created a highly reliable and valid instrument for assessing teaching processes in higher education, offering a robust tool for quality evaluation and enhancement.

Kurbanoğlu and Takunyacı (2017) created and tested the 18-item Physics Laboratory Anxiety Scale (P-LAS) in Turkey to measure how anxious university students are in physics laboratory classes. The instrument was given to 557 university students, and experts looked at it to see if it was valid. They cut it down from 23 items. Exploratory Factor Analysis (EFA) showed a strong one-dimensional structure, with loading values for all 18 items ranging from 0.58 to 0.80 and accounting for 52% of the total variance. A KMO value of 0.93 and a significant Bartlett's Test ($p < 0.001$) showed that the sample was good enough. A Cronbach's alpha coefficient of 0.94 and a split-half correlation of 0.76 showed that the test was very reliable. The item-total correlations ranged from 0.56 to 0.76. This study successfully created a highly reliable and valid one-dimensional instrument for evaluating physics laboratory anxiety, offering a significant resource for physics education research and practice in Turkey.

Ahmad et al. (2024) in Qatar created and validated the STEM Interest Scale (SIS) to measure various psychological factors influencing undergraduates' interest in STEM fields. The research encompassed two phases: Phase I engaged 280 participants for Exploratory Factor Analysis (EFA), and Phase II involved 266 students for Confirmatory Factor Analysis (CFA) and the assessment of nomological validity. EFA identified four factors (intrinsic motivation, self-efficacy, self-concept, employment aspiration) that accounted for 55.7% of the total variance, yielding a KMO of 0.830 and a significant Bartlett's Test ($p < 0.001$). CFA validated these factors, demonstrating strong model fit (e.g., $\chi2 = 242.67$, $\chi2/df = 2.129$, RMSEA = 0.046, CFI = 0.941). The reliability was high, with Cronbach's alpha for the sub-dimensions ranging from 0.680 to 0.758 and an

overall composite reliability (CR) of 0.803. An Average Variance Extracted (AVE) of 0.506 (CR > AVE > 0.5) showed that convergent validity was true. This study offers a comprehensive, multi-faceted tool for comprehending and promoting STEM interest among undergraduates.

Freda et al. (2021) created and tested the SInAPSi Academic Engagement Scale (SAES) to find out how engaged university students in Italy were in their studies. The study comprised a principal sample of 680 first-year students and a convenience sample of 312 third-year students. After the first draft of the items and Exploratory Factor Analysis (EFA) on Group 1, Confirmatory Factor Analysis (CFA) on both groups created a better 6-factor, 29-item structure that fit the model well (e.g., Group 2: $\chi 2/df=1.586$, CFI=0.952, RMSEA=0.043; Group 1: $\chi 2/df=1.849$, CFI=0.965, RMSEA=0.035). The instrument exhibited robust convergent validity (with the majority of AVEs exceeding 0.50 and all CRs surpassing 0.70) as well as discriminant validity. The reliability was acceptable, as the factor-specific Cronbach's alphas varied from 0.70 to 0.90 for Group 1 and from 0.78 to 0.90 for Group 2. Positive correlations with the University Student Engagement Inventory (USEI) showed that construct-related validity was supported. Positive correlations with academic motivation, confidence, and performance showed that criterion-related validity was confirmed. This study offers a psychometrically robust tool for evaluating academic engagement within the Italian university setting.

2.3.2.3 Gaps in Existing Instrumentation and Justification for the Current Study

The review of existing instruments highlights significant contributions to physics education and psychological measurement within educational contexts. However, several critical gaps emerge, underscoring the necessity for the present study. Firstly, while instruments like the diagnostic test for wave material by Asriadi and Sanam (2025) and the HeTMAI by Sukarelawan et al. (2021) demonstrate strong psychometric properties in assessing specific physics concepts or metacognition, and the FCI by Japashov et al. (2024) assesses knowledge about force concepts, none specifically delve into the nuanced conceptual and procedural challenges unique to atomic and nuclear physics at the senior high school level in the Ghanaian context. The highly abstract, counter-intuitive nature, and specialised concepts of atomic and nuclear physics warrant a dedicated instrument that captures these specific learning obstacles.

Secondly, existing instruments, particularly concept inventories, primarily diagnose misconceptions or assess understanding. There is a limited number of tools that systematically and comprehensively explore the underlying factors (e.g., pedagogical practices, curricular design, student-related affective or cognitive attributes beyond metacognition) that account for these learning difficulties. While instruments such as the BRAINS Survey by Summers and Abd-El-Khalick (2018), the revised CLASS by Badeo and Duque (2023), the PLSE by Appiah-Twumasi et al. (2022), the instrument by Setiawan et al. (2024), the P-LAS by Kurbanoğlu and Takunyacı (2017), the SIS by Ahmad et al. (2024), the SAES by Freda et al. (2021), and the Turkish CLASS by Kaltakci-Gurel (2021) effectively measure attitudes, interest, engagement, anxiety, and

self-efficacy, or evaluate teaching processes, they do not directly link these psychological factors to specific content-related challenges in a complex physics domain such as atomic and nuclear physics, nor do they comprehensively identify other influencing factors. The current study aims to address this by developing an instrument that explicitly measures both the challenges and the contributing factors concurrently.

Thirdly, there is a notable absence of instruments that integrate the assessment of both specific content-related challenges and their accounting factors within a single, psychometrically validated framework for this precise domain and target population (senior high school students in Ghana). Such an integrated approach is vital for developing targeted and effective pedagogical interventions. Lastly, psychometric properties and the relevance of measurement tools can vary significantly across different cultural and educational settings. The study by Appiah-Twumasi et al. (2022) is a valuable step in validating a physics self-efficacy instrument within the Ghanaian context, but it does not focus on atomic and nuclear physics challenges or the broader accounting factors. This further underscores the need for a locally relevant and validated tool specific to these content areas.

In light of these identified gaps, the present study is crucial. It aims to develop and rigorously validate an instrument that comprehensively identifies the challenges senior high school students encounter in atomic and nuclear physics and systematically explores the multifactorial influences accounting for these difficulties. By employing robust psychometric methodologies for validity and reliability, this study will provide a much-

needed, contextually relevant, and psychometrically sound tool. This instrument will not only facilitate deeper understanding of student learning in this critical physics domain but also serve as a foundation for evidence-based improvements in teaching practices and curriculum design in Ghana.

2.3.3 Relative Impact of Factors Affecting Student Learning in Physics/STEM

In addition to recognising the various factors that affect student learning, a crucial element in comprehending the challenges in physics education is evaluating the relative influence of these factors. This part looks at real-world studies that have measured the different effects of student-related, teacher-related, curriculum-related, and subject-related factors on student learning outcomes, academic performance, or perceived difficulties in physics and other STEM fields. Although few studies directly measure the specific effects of factors on challenges in atomic and nuclear physics, research utilising statistical techniques such as regression analysis and Structural Equation Modelling (SEM) offers significant insights into the predictive efficacy of various influences on learning processes and academic achievement. These studies, which are mostly about general physics or science, help us understand which factors have the biggest effect. This helps us understand the goal of the current study, which is to find and measure accounting factors in the specific area of atomic and nuclear physics.

Taslidere (2020) did a study to find out and predict how well 12^{th} -grade students in Turkey would do in physics based on a few cognitive, emotional, personal, and socioeconomic factors. The study used multiple regression analysis on a sample of 496

students from 18 high schools to figure out how much each of these factor sets affected physics achievement, which was measured by scores on a national examination. The results showed that cognitive traits, such as science grades and physics course grades, accounted for the most variance, with 60.6% of the variance in physics achievement when looked at alone. Adding affective traits like interest in physics, motivation, and self-efficacy made a big difference in the model, accounting for 2.3% of the explained variance. Some personal traits, like gender and how students feel about teacher-led activities, also explained a little more variance, but none of the socioeconomic variables were found to be significant predictors. In total, the comprehensive model that included all cognitive, affective, personal, and socioeconomic factors explained 64% of the total variance in physics achievement. This indicates that cognitive factors are the primary predictors of physics achievement, while affective and personal factors exert smaller, yet significant, influences.

Appiah-Twumasi (2024) also looked at how attitude, self-efficacy, and personality traits affect the academic performance of high school students in physics in the Berekum East Municipality of Ghana. They used a multistage random sampling method to choose 210 research subjects from three high schools. Three standardised questionnaires served as primary data sources: Attitude Towards Physics Learning (ATPL), Physics Learning Self-Efficacy (PLSE), and Students' Personality Trait Inventory (SPTI). Additionally, Students' Physics Mock Examinations scores were utilised as a secondary data source. Data collection and analysis were conducted through multiple regression. The findings indicated a combined effect of 21.100% of the variance in attitude, self-efficacy, and

personality traits on the prediction of students' academic performance in physics. The study also showed how these factors affected each other: Students' personality traits were the most significant predictors of academic performance in physics ($\beta = 0.232$, $p < 0.050$), followed by self-efficacy ($\beta = 0.192$, $p < 0.050$), and then attitude ($\beta = 0.121$, $p < 0.05$). This shows that all three factors are important predictors, but personality traits had the biggest positive effect on physics performance in Ghana.

Mansour et al. (2024) investigated the multifactorial influences on the academic performance of 951 tenth-grade students in STEM subjects (physics, chemistry, biology, mathematics ematics, and information technologies) across public and private schools in two provinces in Turkey. Employing a correlational research model, the study evaluated the influence of students' personal attributes, teacher efficacy, and school characteristics on achievement in STEM courses. The 'Factors Affecting STEM Achievement Questionnaire (FA-STEM-A)' was used to collect data. It has 20 questions and is split into three sub-dimensions. SEM showed that having positive traits as a student, like liking STEM subjects and being confident in STEM skills, can moderately boost achievement.

On the other hand, things that teachers and schools do wrong, like not having enough activities in the classroom, not having enough technology, and having too many students in a class, make it worse. The results show the exact direct relative contributions: school features had the biggest negative direct effect on STEM achievement ($\beta = -0.33$, $p < 0.01$) because of things like not enough classroom activities, not enough technology, and

too many students in each class. Personal characteristics of students had a significant positive direct effect on STEM achievement ($\beta = 0.18$, $p < 0.01$), arising from factors such as enthusiasm for STEM subjects and self-assurance in STEM skills. Moreover, teacher effect demonstrated a significant negative direct impact on academic performance ($\beta = -0.14$, $p < 0.01$). This comprehension of the direct effects elucidates the distinct roles of these factors, with school characteristics exerting the most significant negative direct influence on STEM education outcomes, succeeded by adverse teacher effects, while student attributes yield positive contributions.

Ajadi and Amoo (2024) examined the influence of academic self-efficacy, achievement motivation, and emotional intelligence on the academic performance of 300 secondary school students in Physics in Ogbomoso, Oyo State, Nigeria. The study employed multiple regression analysis, demonstrating that these three psychological factors collectively and significantly predicted students' physics achievement, explaining 56.5% of the variance in their scores (Adjusted $R = 0.565$, $F(3, 295) = 131.230$, $p = 0.001$). The findings indicate that academic self-efficacy was the most robust positive predictor ($\beta = 0.754$, $p=0.000$). Next came academic achievement motivation ($\beta = 0.391$, $p = 0.002$) and emotional intelligence ($\beta = 0.233$, $p = 0.004$), both of which had big positive effects on physics achievement. These findings underscore the primary influence of students' self-beliefs and motivational drives on their academic success in physics, with self-efficacy exhibiting the most significant individual effect.

Atchia and Chinapah (2023) created a SEM to show how important contextual factors are related to the academic success of 600 secondary school students in Mauritius. The produced SEM exhibited favourable fit indices, with a p-value of 0.000 for the regression weights, signifying significance for all effects. The findings indicate that the direct standardised causal effects on students' academic achievement were as follows: school leadership had the most significant impact ($\beta = 0.43$), followed by the student factor ($\beta = 0.30$), the teacher factor in tuition ($\beta = 0.15$), the teacher factor in school ($\beta = 0.09$), and lastly, the socio-economic factor ($\beta = 0.03$). This study underscores the intricate interactions among diverse factors within the educational ecosystem, accentuating the critical influence of leadership and student-centered components on academic achievement, while offering definitive quantitative assessments of their respective impacts.

Tong et al. (2025) used SEM to look at how mathematics skills affected the ability of 1,878 grade 12 students in Southern China to solve physics problems. The findings indicate that the mathematics ematical competencies influencing high school students' physics problem-solving abilities can be classified into two primary subskills: algebraic skills and geometric skills. The standardised coefficients of the pathways from overall mathematics ematics skills to these subskills in physics problem-solving (with p-values of 0.000, indicating significance) demonstrated their relative causal effects. Algebraic skills had a stronger direct effect ($\beta = 0.797$) on how well students solved physics problems than geometric skills ($\beta = 0.737$). This means that for every one-point increase in a student's mathematics skills, their scores on physics problems that require algebraic

skills go up by 0.797 points, and their scores on problems that require geometric skills go up by 0.737 points. This study highlights the pivotal importance of particular mathematics ematical competencies, especially algebraic skills, as key indicators of success in resolving physics problems.

2.3.3.1 Gaps in the Literature and Rationale for Assessing the Relative Impact of Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics

The preceding review has synthesised existing empirical studies on various factors influencing student learning and academic performance in physics and broader STEM disciplines. While these studies provide a robust foundation for understanding the predictors of achievement, several critical gaps remain, particularly concerning the specific focus of this study on challenges in atomic and nuclear physics. These gaps highlight the unique contribution intended by Research Question 4.

A significant limitation of the current literature is its predominantly general focus on physics achievement or STEM performance. While broad factors like cognitive characteristics, self-efficacy, motivation, personality traits, and mathematics ematics skills are identified as predictors, there is a distinct scarcity of studies that specifically investigate factors influencing challenges or difficulties within specialised areas such as atomic and nuclear physics. The unique conceptual demands, abstract nature, and potential misconceptions associated with atomic and nuclear physics concepts may mean

that the general findings from broader physics contexts are insufficient to fully explain the challenges students face in this particular domain.

Furthermore, most reviewed studies quantify the impact or prediction of factors on academic performance or achievement. However, few studies directly delve into the qualitative or quantitative nature of specific challenges students encounter in learning complex physics topics. Understanding the precise nature of these challenges, beyond simply identifying factors that correlate with low achievement, is crucial for developing targeted pedagogical interventions. Research Question 4 is therefore necessary to bridge this gap by explicitly identifying and characterizing these challenges.

Lastly, while studies from diverse geographical contexts (Turkey, Ghana, Mauritius, China) have been reviewed, the findings, while valuable, may not fully capture the specific contextual nuances related to learning atomic and nuclear physics within the researcher's local educational setting. Differences in curriculum, instructional methods for advanced topics, teacher training, and available resources pertinent to atomic and nuclear physics can all introduce unique challenges that warrant focused investigation. In light of these gaps, Research Question 4 is essential to provide a targeted and in-depth understanding of the specific challenges students encounter in atomic and nuclear physics, thereby complementing the broader insights from existing research on general physics and STEM achievement. This focused inquiry will enable the identification of domain-specific obstacles, paving the way for more effective teaching and learning strategies in this specialised area.

2.4 Summary of Literature Review

The literature review establishes a robust foundation for understanding SHS students' challenges in atomic and nuclear physics through CLT, SCT, and CTT. CLT explains cognitive barriers due to high intrinsic and extraneous loads from abstract concepts and poor instructional design, aligning with studies reporting misconceptions, mathematics ematical difficulties, and procedural gaps (Morales & Tuzón, 2020; Sartika & Humairah, 2018; Reddy & Panacharoensawad, 2017). These findings highlight the need to manage cognitive load through strategies like worked examples and visualisations (Chew & Cerbin, 2021). However, the severity and specificity of challenges in atomic and nuclear physics, particularly in Ghana, remain underexplored, justifying the first research question.

SCT elucidates factors contributing to challenges, emphasising reciprocal interactions among personal (self-efficacy, attitudes), environmental (resources, teaching), and behavioural factors. Empirical studies identify abstract content, ineffective pedagogy, resource scarcity, and low motivation as barriers (Çermik, 2020; Coffie et al., 2020; Wangchuk et al., 2023). While these align with SCT's framework, few studies focus on atomic and nuclear physics, and assessment-related factors are rarely highlighted, supporting the need for the second research question to explore these in a Ghanaian context.

CTT underpins the psychometric validation of instruments, ensuring reliable and valid measurement of challenges and factors. Studies demonstrate robust psychometrics for

physics-related tools (Asriadi & Sanam, 2025; Appiah-Twumasi et al., 2022), but none specifically target atomic and nuclear physics challenges in Ghana. This gap necessitates the third research question to develop and validate a contextually relevant instrument, ensuring credible data for the study's findings.

The relative impact of factors, guided by SCT, is critical for prioritising interventions. Studies show cognitive, affective, and environmental factors influence physics/STEM outcomes, with varying contributions (Taslidere, 2020; Appiah-Twumasi, 2024; Ajadi & Amoo, 2024). However, the lack of research on atomic and nuclear physics-specific challenges limits understanding of which factors dominate in this domain, particularly in resource-constrained settings like Ghana. The fourth research question addresses this gap, aiming to quantify the impact of identified factors to inform targeted educational strategies.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter outlines the methodological framework utilised to tackle the research questions of this study. It starts with a discussion of the research paradigm and then goes into great detail about the research design, study population, sampling procedures, instrumentation, data collection methods, and data analysis techniques. The study also talks about ethical issues that are important.

3.1 Study Area

The study was conducted in Ghana's Ashanti Region, specifically in the Atwima Nwabiagya Municipal. The Atwima Nwabiagya Municipal Assembly (see Figure 3.1) is one of the 43 Administrative Municipals in the Ashanti Region. It was formerly called the Atwima Nwabiagya District Assembly, but the government of Ghana made it a municipality in 2018. There are about 64 settlements in the Municipal, with Nkawie as the administrative capital. About 35.3% of the settlements are urban and 64.7% are rural (Ghana Statistical Service, 2021).

The Atwima Nwabiagya Municipal is located between 1° 45' and 2° 00' West and 6° 32' and 6° 75' North. The Municipal is in the western part of the Region. It shares borders with Ahafo Ano South and Atwima Mponua Districts to the West, Offinso Municipal to the North, Amansie–West and Atwima Kwanwoma Districts to the South, and Kumasi

Metropolis and Afigya Kwabre Districts to the East. The area it covers is about 294.84 square kilometres. Nkawie is the capital of the Municipal. The Municipal has 181 kindergarten/nursery schools, 183 primary schools, 123 junior high schools, and 5 senior high schools. The district also has four vocational schools and one theological university (Ghana Statistical Service, 2021).

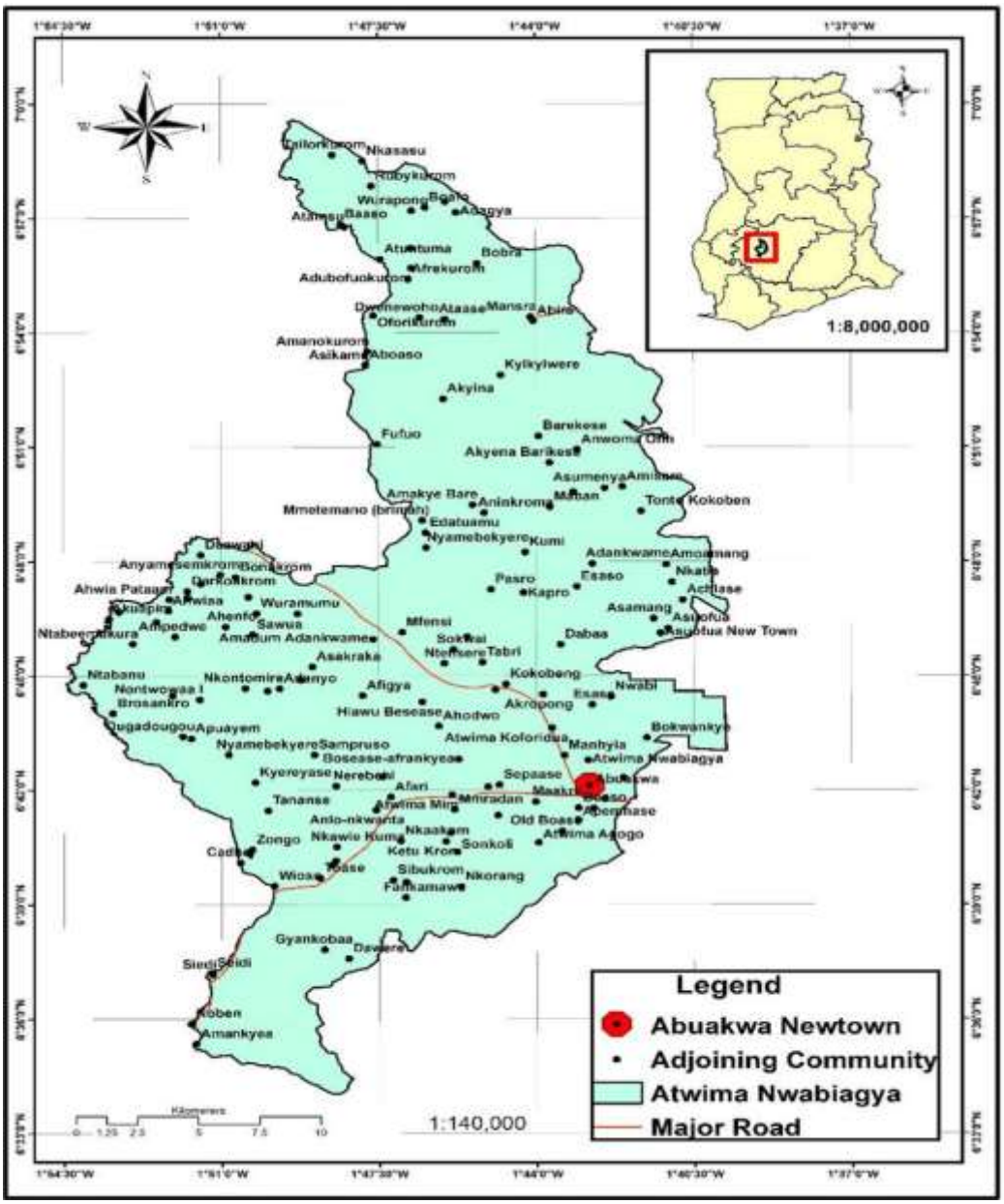

Figure 3.1: A Map of the Study Area [Adopted from Kaamah et al. (2023)]

3.2 Research Paradigm

This study is underpinned by a pragmatic research paradigm. Pragmatism, as a philosophical stance, eschews commitment to a single philosophical system, instead focusing on the practicality and utility of research approaches in addressing specific research problems (Clarke & Visser, 2018). It posits that the most effective research involves using whatever methods work best to understand the phenomenon under investigation (Creswell, 2009). This paradigm, according to Creswell (2009), is particularly well-suited for mixed-methods research, as it offers a flexible framework that acknowledges the value of both quantitative and qualitative data in providing a more comprehensive understanding of a complex issue.

The choice of pragmatism is justified by the multifaceted nature of students' challenges in atomic and nuclear physics. Understanding these challenges requires not only identifying the prevalence and relationships between various factors (quantitatively) but also delving into the nuanced experiences and perceptions of students qualitatively. A purely positivist approach, focused solely on objective measurement, would likely miss the rich contextual details that influence learning difficulties. Conversely, a purely interpretivist approach, while yielding deep insights, might struggle to generalise findings across a larger population.

Pragmatism bridges this gap by allowing the researcher to utilise the strengths of both quantitative and qualitative methods. It prioritises the research question and the most effective means to answer it, rather than adhering rigidly to a single philosophical

doctrine. This allows for a holistic investigation, where qualitative data can explore the depth and context of experiences, and quantitative data can establish patterns, relationships, and the generalisability of findings, thereby yielding more actionable and contextually relevant insights for the Ghanaian educational landscape.

3.3 Research Design

The study adopted a mixed-methods research design, specifically an exploratory sequential design (QUAL→QUAN), to comprehensively investigate the challenges and factors accounting for students' challenges in atomic and nuclear physics. This design, according to Creswell (2012), involved two distinct phases. In the first phase, qualitative data were collected and analysed to thoroughly explore the phenomenon and identify underlying themes. The findings from this initial qualitative phase then explicitly informed the development and focus of the subsequent quantitative phase, where structured data were collected to measure the prevalence and relationships of the identified themes across a larger sample.

The rationale for employing an exploratory sequential mixed-methods design is rooted in its capacity to provide a robust and triangulated understanding of the complex research problem (Creswell, 2014). The initial qualitative phase, through in-depth interviews, served as a crucial exploratory stage. Its primary aim was to gain a rich, nuanced understanding of students' lived experiences and perceptions, allowing for the identification of prominent challenges and underlying factors contributing to learning challenges in atomic and nuclear physics. This in-depth exploration ensured that the

subsequent quantitative instrument (the questionnaire) would be empirically grounded and directly relevant to the actual challenges faced by students, and their contributing factors. The themes and insights gleaned from this qualitative data directly informed the development and structuring of the questionnaire items.

The subsequent quantitative phase, through the administration of the questionnaire, then allowed for the precise measurement of these identified factors across a larger student population, enabling the identification of general challenges and their contributing factors, and the relative importance of different factors. This sequential approach, moving from in-depth qualitative exploration to broad quantitative measurement, facilitates the corroboration, elaboration, and expansion of findings from both data types. The triangulation of insights derived from both qualitative and quantitative strands significantly enhances the credibility, validity, and comprehensiveness of the overall study's findings regarding students' challenges in atomic and nuclear physics within the specific context of Ghanaian senior high schools.

3.4 Population

The study's target population consisted of all senior high school students enrolled in atomic and nuclear physics within the Atwima Nwabiagya Municipality. Because the study was focused on understanding learning difficulties, only students who were currently studying or had finished studying relevant topics in atomic and nuclear physics were allowed to participate.

3.5 Sampling Procedures

A multi-stage sampling technique was employed to select the study participants. In the first stage, purposive sampling was used to select all five senior high schools in the Atwima Nwabiagya Municipal. This comprehensive inclusion was based on ensuring full representation of the educational context within the municipality.

For the qualitative phase, a purposive subsample of students was selected from the chosen schools to participate in the in-depth interviews. Data collection for this phase continued until thematic saturation was achieved, meaning no new themes or significant insights emerged from additional interviews. This iterative process resulted in a final sample of 24 students for the qualitative interviews. This emergent sample size is generally considered adequate in qualitative studies to achieve rich data and saturation, particularly when exploring a relatively focused phenomenon within a specific context (Leavy, 2017; Onwuegbuzie & Collins, 2007). The selection aimed for diversity in perspectives on learning experiences.

For the quantitative phase, a larger sample of 584 students was selected from the participating schools. This sample size was determined based on the requirements for conducting Confirmatory Factor Analysis (CFA), a statistical technique utilised in this study for psychometric validation. With an initial questionnaire comprising 55 items, a sample-to-item ratio of approximately 10:1 to 20:1 is commonly recommended for CFA to ensure robust parameter estimates and model fit (Hair et al., 2021; Hoyle & Gottfredson, 2015; Praharaj & Ameen, 2024; Rahman, 2023). A sample size of 584 yields

a ratio of approximately 10:1 (584 participants / 55 items), which is considered a strong minimum for reliable CFA results. Participants were selected from the eligible student population across the chosen schools to ensure broad representation.

3.6 Instrumentation

Three primary instruments were utilised for data collection in this study: a semi-structured interview guide, a questionnaire designed to assess students' challenges in atomic and nuclear physics, and a separate questionnaire focusing on the factors contributing to these challenges.

3.6.1 Interview Guide

The semi-structured interview guide (see Appendix A) was the initial instrument used in this study, designed to explore students' experiences and challenges in atomic and nuclear physics in an open-ended manner. This exploratory phase was crucial for identifying the prominent themes and underlying factors contributing to learning challenges, which subsequently informed the development and structuring of the quantitative questionnaire. The guide, titled "Interview Guide for Exploring Student Experiences in Atomic and Nuclear Physics" as detailed in Appendix A, covered broad areas such as specific conceptual challenges, teaching methods, learning resources, student attitudes, and assessment experiences. The interview began with an introduction explaining the study's purpose, assuring confidentiality, and setting expectations for the interview duration. It concluded with an opportunity for participants to ask final questions.

3.6.2 Students' Challenges and Factors Questionnaire

Following the in-depth insights gained from the qualitative interviews, two initial questionnaires were designed to quantitatively assess students' challenges and the factors accounting for these challenges in atomic and nuclear physics. Both instruments were structured around a 5-point Likert scale, ranging from 'Strongly Agree' (SA) to 'Strongly Disagree' (SD).

Initially, the "Questionnaire for Students' Challenges in Atomic and Nuclear Physics" comprised 25 items (see Appendix B). The items were categorised into three challenge dimensions: Conceptual Understanding Challenge (CUC) (9 items), Problem-Solving and Application Challenges (PSC) (9 items), Mathematics ematical Demands Challenges (MDC (7 items). After rigorous psychometric procedures, the final version comprised 12 items (see Appendix C), with the following dimensions: Conceptual Understanding Challenge (CUC) (4 items), Problem-Solving and Application Challenges (PSC) (4 items), Mathematics ematical Demands Challenges (MDC (4 items).

Also, the initial form of the "Questionnaire for Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics" (see Appendix D) comprised 30 items. The items were categorised into four main factors: Teaching Method (TM) (7 items), Learning Resources (LR) (8 items), Students' Attitude and Interest (SAI) (9 items), and Assessment and Evaluation (AE) (6 items). However, this initial form was reduced to 17 items (see Appendix E) after rigorous psychometric processes, with the following factors: Teaching Method (TM) (5 items), Learning

Resources (LR) (4 items), Students' Attitude and Interest (SAI) (4 items), and Assessment and Evaluation (AE) (4 items).

3.7 Validity

The validity of a research instrument refers to the extent to which it accurately measures what it is intended to measure (Heale & Twycross, 2015). In this study, validity was determined for the interview guide and the questionnaires.

3.7.1 Validity of the Interview Guide

To ensure the validity of the interview guide, content validity was established through expert review. The interview guide was reviewed by two qualitative research experts and two physics education specialists to ensure that the questions were clear, unambiguous, relevant to the research questions, and capable of eliciting rich data pertaining to students' experiences and difficulties in atomic and nuclear physics. Their feedback led to refinements in question wording and sequencing to enhance clarity and appropriateness. This expert review process helped to ensure that the interview guide was comprehensive in its coverage of the intended areas of inquiry.

3.7.2 Validity of the Questionnaires

To ensure the questionnaires accurately measured the intended constructs related to students' challenges encountered in the study of atomic and nuclear physics, content validity, construct validity, convergent validity, and discriminant validity were rigorously assessed. Content validity was established through a panel of three subject matter experts

(experienced physics educators from Ghanaian universities and senior high schools) who reviewed all questionnaire items for relevance, clarity, comprehensiveness, and appropriateness for the target student population. Their feedback was used to refine the initial item pool, leading to modifications in wording and item inclusion to ensure adequate coverage of the domain.

The construct validity was primarily determined through exploratory factor analysis (EFA) conducted on data from a pilot study with 257 physics students. This analysis helped to find the questionnaire's underlying factor structure, which showed that the tool accurately measured the constructs it was meant to measure. The pilot test validated the data's appropriateness for factor analysis, yielding a Kaiser-Meyer-Olkin (KMO) value of 0.766, deemed "meritorious" (Pallant, 2011). Bartlett's test of sphericity also gave a significant result ($\chi^2 = 8113.882$, $df = 210$, $p = 0.001$), which further showed that the dataset was appropriate.

The initial analysis revealed seven factors with eigenvalues greater than 1, which collectively explained 66.979% of the total variance, indicating a robust underlying structure. These summarised results provide an initial confirmation of the questionnaire's construct validity. A more detailed presentation of the full psychometric evidence, including specific factor loadings, model fit indices from confirmatory factor analysis (CFA), and other relevant statistics that directly address Research Question 3, is provided in Chapter 4 (section 4.3).

3.8 Pilot-Testing

Pilot testing, or a pilot study or a feasibility study, is a small-scale test of a research project, survey, or intervention before it is fully put into action (Zailinawati et al., 2006). It helps researchers find and fix problems, improve their methods, and make sure the main study is a success.

3.8.1 Pilot Testing of the Interview Guide

We did a pilot test of the interview guide with 15 students who were similar to the people we wanted to study but weren't part of the main study group. The goal of this pilot testing was to find any unclear questions, check the flow and timing of the interview, and see if the questions got the right amount of information. Feedback from the pilot participants and things that were noticed during the pilot interviews led to small changes in the wording of some questions to make them clearer and to improve the interview process before the main data collection started.

3.8.2 Pilot Testing of the Questionnaire

A pilot test of the questionnaires was conducted with 73 SHS physics students from a school outside the main study sample. The purpose of this pilot testing was to identify any ambiguities in the questionnaire items, assess the clarity of instructions, check for potential response biases, and estimate the time required for completion. Based on the pilot results, minor adjustments were made to improve clarity and flow of the questionnaire items.

3.9 Reliability

The reliability of a research instrument refers to the consistency and stability of its measurements (O'Connor & Joffe, 2020). In simpler terms, it is about whether an instrument will produce the same (or very similar) results if used repeatedly under the same conditions with the same subjects or phenomena.

3.9.1 Reliability of the Interview Guide

For qualitative research, "reliability" is often framed in terms of "dependability" and "confirmability" (Leavy, 2017). To ensure the dependability of the interview data, detailed interview protocols were established, including a consistent introduction and clear guidelines for probing questions. All interviews were conducted by the same interviewer, ensuring consistency in delivery and interaction style. To enhance confirmability, a clear audit trail of data collection and analysis procedures was maintained. This included detailed notes on interview contexts, recording of interviews (with participant consent), and systematic transcription. These measures ensured that the qualitative data collection process was consistent and transparent, allowing others to trace the research steps and verify the findings.

3.9.2 Reliability of the Questionnaire

To make sure that the items in each identified factor consistently measured the same construct, the reliability of the questionnaire, specifically its internal consistency, was tested. Cronbach's Alpha (α) and McDonald's Omega (ω) were used to check for internal consistency. We used the data from the pilot study to figure out these coefficients for the

whole scale and for each subscale. The computed **α** and **ω** values for each subscale, offering additional empirical validation of the questionnaire's reliability, in response to research question 3, are elaborated upon in Section 4.3.3.

3.10 Data Collection Procedures

The data collection process occurred in two consecutive phases. That is, collecting qualitative data through interviews and then collecting quantitative data through questionnaires. During the qualitative phase, semi-structured interviews were conducted with a purposively selected subsample of students. The interviews took place in a private and quiet area of the school, which made sure that the participants were comfortable and that their privacy was protected. All interviews were audio-recorded with the participants' clear permission. Field notes were also written down during and right after each interview to record non-verbal cues and other important details.

For the quantitative phase, questionnaires were given to the chosen students during school hours, in a place where they could focus on finishing them, after the qualitative data analysis had helped shape the final questionnaire design. The researcher was available to clarify any questions, and the instructions were clear. Participants were guaranteed anonymity and confidentiality, and the voluntary nature of their participation was underscored. As soon as the questionnaires were finished, they were collected.

3.11 Data Analysis

Data analysis began following the conclusion of both phases of data collection, employing specific methodologies for each research question. To find out what problems high school seniors have when learning and teaching atomic and nuclear physics (research question 1), thematic analysis was employed to look at the qualitative data from the interviews. The goal of this process was to find the main problems. For the quantitative component, descriptive statistics, encompassing means and standard deviations, were computed for the items within each challenge dimension, as well as for the overall dimensions of challenges derived from the final iteration of the "Questionnaire for Students' Challenges in Atomic and Nuclear Physics." An adapted scale from Pimentel (2019) was used to understand what these mean scores meant.

To ascertain the factors contributing to students' difficulties in the teaching and learning of atomic and nuclear physics (research question 2), thematic analysis of interview transcripts was performed to uncover the underlying elements influencing these challenges. The emergent themes were utilised for the quantitative analysis in research question 4. To find out how much psychometric evidence there is to support the reliability and validity of the factors that explain students' problems with atomic and nuclear physics (research question 3), exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) on the questionnaire data were employed. This included looking at the Kaiser-Meyer-Olkin (KMO) measure, Bartlett's Test of Sphericity, eigenvalues, and the percentage of variance that the identified factors explained. I also looked at reliability by using internal consistency measures like Cronbach's Alpha (α) and McDonald's Omega

(ω). Average Variance Extracted (AVE) and Composite Reliability (CR) were used to check for convergent validity, and the Heterotrait-Monotrait Ratio (HTMT) of correlations to check for discriminant validity.

Relative weight analysis (RWA) was used to figure out how much each factor affected students' problems with learning and teaching atomic and nuclear physics (research question 4). This advanced statistical method measured how much each predictor variable (Content Difficulty, Teaching Strategy, Learning Resources, Students' Attitude and Interest, and Assessment and Evaluation) added to the overall difference in how students saw their problems with atomic and nuclear physics.

RWA was chosen over traditional regression coefficients because it provides a more accurate and interpretable measure of the unique contribution of each predictor variable when predictors are correlated (Garver & Williams, 2019). This allows for a clear understanding of the practical significance of each factor in explaining the variability in students' challenges. The dependent variable for this analysis was a composite score representing students' overall challenges, derived from the three challenge dimensions (Conceptual Understanding Challenges, Problem-Solving and Application Challenges, and Mathematics ematical Demands Challenges) identified in the final challenges questionnaire.

3.12 Ethical Considerations

During the study, strict rules about ethics were followed. All participants gave their informed consent. Before any data collection, the Institutional Review Board (IRB) of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) reviewed and approved the study protocol. After that, the Municipal education directorate and the heads of the chosen senior high schools gave their permission. Participants were also fully informed about the study's purpose, the steps involved, their right to leave at any time without penalty, and the steps taken to protect their privacy and anonymity. The researcher securely stored all of the data they collected and only they could see it. Participants were assured that their responses would be utilised exclusively for research purposes and would not influence their academic standing.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter presents the results and their discussions. The presentation and discussion of the results were done based on the research questions.

4.1 Results for Research Question 1

The purpose of this research question was to determine the difficulties that SHS physics students face when learning and teaching atomic and nuclear physics. Twenty-four (24) SHS physics students were purposefully chosen, and their experiences with the difficulties they faced were first investigated through qualitative interviews. To quantitatively evaluate the frequency and scope of these identified challenges, a questionnaire was developed based on the insights gathered from this exploratory qualitative phase and then given to a larger sample of students. This integrated approach offered a multifaceted perspective on the challenges students encounter in learning atomic and nuclear physics, enabling both a thorough investigation of the student experience and a wider generalisation of the findings.

4.1.1 Qualitative Results for Research Question 1

The interview data, generated from the 24 Senior High School (SHS) physics students, revealed several key challenges encountered in the teaching and learning of atomic and nuclear physics. These challenges coalesce around three main themes: conceptual

understanding, problem-solving and application, and mathematics ematical demands. Each theme is thoroughly explained below and supported by illustrative quotes from the hypothetical participants.

Theme 1: Conceptual Understanding Challenges

This theme delves into the significant cognitive hurdles students face in internalising the abstract and often counter-intuitive theoretical frameworks of atomic and nuclear physics. A recurring struggle was the inability to visualise or directly observe the subatomic realm, making it difficult to construct accurate mental models of atomic structures, such as electron shells and nuclear compositions. Students frequently expressed bewilderment regarding the probabilistic nature and quantum behaviors of particles, which defy classical intuitions.

The concepts of radioactivity, nuclear decay processes, and the energy transformations involved often lead to confusion, as students struggled to differentiate between various types of decay and comprehend the underlying mechanisms of nuclear instability. Furthermore, the distinction between complex nuclear reactions like fission and fusion, including the conditions under which they occur and the energy implications, remains a significant conceptual barrier. The difficulty in connecting these abstract theories to tangible, real-world phenomena also point to a fragmented understanding, where theoretical knowledge exists in isolation rather than being integrated into a broader scientific worldview. This suggests a need for teaching approaches that bridge the gap between microscopic models and macroscopic observations.

To better illustrate the nuances of these conceptual struggles, the direct voices of the students should be taken into account. The following quotes vividly capture their confusion and difficulty in grasping the core ideas of atomic and nuclear physics:

> "*It is really hard to imagine atoms and electrons because you cannot see them. Like, how does an electron just jump between energy levels? It feels like magic, not science*." - **Student 7**
>
> "*Radioactivity, decay, half-life... all those ideas just mix up in my head. I do not really get what is happening to the nucleus when it decays*." - **Student 12**
>
> "*Fission and fusion always confuse me. I know one splits and one joins, but understanding the energy released and why they happen is difficult*." - **Student 3**
>
> "*The whole wave-particle duality thing makes no sense to me. Is light a wave or a particle? How can it be both at the same time? It is very confusing*." - **Student 19**
>
> "*I find it tough to connect atomic theory with practical applications. We learn about energy levels, but then how does that relate to how a fluorescent light works or something similar in real life*?" - **Student 15**

Theme 2: Problem-Solving and Application Challenges

This theme elucidates the profound difficulties students experience when attempting to translate their theoretical knowledge into actionable solutions for both quantitative and qualitative problems in atomic and nuclear physics. A primary hurdle lies in the initial stage of problem interpretation: according to the participants, they struggle to deconstruct word problems, identify relevant information, and subsequently formulate appropriate mathematics ematical expressions. This often stems from an inability to discern which

specific atomic or nuclear principle or formula is applicable to a given scenario. Even when formulas are correctly identified, students reported significant challenges in accurately applying them, often making errors in the process, which suggests issues with procedural fluency and attention to detail.

Beyond mere calculation, students found it particularly demanding to analyse and interpret experimental data, such as decay curves or energy level diagrams, indicating a gap in their scientific reasoning and graphical literacy skills. Furthermore, the ability to articulate and explain real-world phenomena using the foundational principles of atomic and nuclear physics proves challenging, underscoring a struggle to bridge the gap between abstract physics concepts and their tangible manifestations in the everyday world. The students' difficulties highlight a need for more scaffolded problem-solving instruction and opportunities for authentic application.

The following excerpts from the interviews convey the frustrations students encounter when navigating the problem-solving landscape of atomic and nuclear physics:

> "*When I read a word problem, I just get stuck. I do not know how to start or which formula to even pick to solve it. It is hard to set it up*." - **Student 1**
>
> "*I can memorise the formulas, but when it comes to a new problem, applying them correctly is challenging. I always end up using the wrong one or making a mistake*." - **Student 10**

"*Analysing those graphs of decay curves or energy levels... I do not know what they mean or how to get information from them. It is hard to interpret experimental data*." - **Student 22**

"*I find it hard to explain real-world phenomena using atomic and nuclear physics principles. Like explaining how a nuclear power plant works using what we learned in class is very difficult for me*." - **Student 5**

"*Even if I try to solve a problem, I often make errors when performing calculations for atomic and nuclear physics problems. Especially with all the powers of ten and scientific notation, it is frustrating*." **- Student 17**

Theme 3: Mathematics ematical Demands Challenges

This theme illuminates the specific and pervasive difficulties students encounter due to the intrinsic mathematics ematical complexity embedded within atomic and nuclear physics. A significant barrier is the perception that the equations used are overly complicated, which often points to an insufficient foundational understanding or mastery of prerequisite mathematics ematical skills such as algebra, logarithms, and basic calculus. Students frequently struggle with the accurate performance of calculations, particularly those involving exponents, scientific notation, and significant figures, where small errors can lead to vastly incorrect results. Beyond raw computation, the interpretation and effective use of various graphical representations, such as decay curves and energy level diagrams, pose considerable challenges, indicating difficulties in translating visual data into meaningful physical insights.

Furthermore, the abstract nature of the mathematics ematical constructs themselves, detached from concrete physical analogs, often exacerbates the learning process, making it difficult for students to connect the mathematics ematical models with the underlying physical realities. The challenges also extend to understanding the derivations of mathematics ematical formulas, suggesting that a lack of insight into why certain equations are structured the way they are impedes deeper comprehension and application. This theme underscores the critical interdependency between mathematics ematical proficiency and success in atomic and nuclear physics.

The following quotes reveal their struggles with the quantitative aspects of atomic and nuclear physics:

> "*The mathematical equations used in atomic and nuclear physics are too complicated for me. There are so many symbols and weird numbers, it is just overwhelming*." - **Student 4**
>
> "*I really struggle with the mathematics. I think I lack the necessary mathematical background like algebra and logarithms for atomic and nuclear physics. Especially with those big or tiny numbers and powers, it gets confusing*." - **Student 9**
>
> "*Understanding derivations of mathematical formulas in atomic and nuclear physics is challenging. We just get given formulas, but I do not understand how they got there, which makes it harder to use them*." - **Student 14**

"*When we have to use graphs, like those decay curves, I find it difficult to interpret and use graphs related to atomic and nuclear processes. I do not know what they are showing me or how to get values from them*." - **Student 20**

"*Performing calculations involving exponents, scientific notation, and significant figures accurately is a challenge. I always mess up the decimal points or the powers of ten*." - **Student 6**

The qualitative interview findings underscore that senior high school physics students face significant and interconnected challenges in atomic and nuclear physics, primarily revolving around the abstract nature of the concepts, the intricate demands of problem-solving, and the foundational mathematical skills required. The emergent themes of conceptual understanding challenges, problem-solving and application challenges, and mathematical demands challenges consistently highlight students' struggles with visualisation, application, and quantitative manipulation.

4.1.2 Quantitative Results for Research Question 1

This section presents the quantitative findings (means and standard deviations) regarding the challenges encountered by 400 Senior High School (SHS) physics students in the teaching and learning of atomic and nuclear physics, as measured by the final "Students' Challenges Questionnaire", which was refined after the exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The interpretation of mean scores is guided by the adapted scale developed by Pimentel (2019): 1.00 – 1.79 ('very low challenge'), 1.80 – 2.59 ('low challenge'), 2.60 – 3.39 ('moderate challenge'), 3.40 – 4.19 ('high

challenge'), and 4.20 – 5.00 ('very high challenge'). The results are presented in Table 4.1.

Table 4.1: Mean, Standard Deviation, and Interpretation of Perceived Challenges in Atomic and Nuclear Physics

Challenge Dimension	Item	Mean	SD	Interpretation
Conceptual Understanding Challenges (CC)		**4.30**	**0.751**	**very high challenge**
	I find the relationship between energy levels and electron transitions confusing.	4.19	0.923	very high challenge
	The concepts of radioactivity and decay processes are hard to understand.	4.27	0.946	very high challenge
	I find it hard to connect atomic theory with practical applications.	4.31	0.918	very high challenge
	I have difficulty understanding the laws governing nuclear energy production.	4.43	0.990	very high challenge
Problem-Solving and Application Challenges (PSC)		**4.27**	**0.676**	**very high challenge**
	Applying formulas and equations correctly to solve complex atomic and nuclear physics problems is challenging.	4.24	0.852	very high challenge
	I have difficulty analysing and interpreting experimental data in atomic and nuclear physics.	4.21	0.930	very high challenge
	It is hard for me to explain real-world phenomena using atomic and nuclear physics principles.	4.26	0.877	very high challenge

	I find it difficult to translate word problems into mathematics ematical expressions in this subject.	4.38	0.946	very high challenge
Mathematics ematical Demands Challenges (MDC)		**4.21**	**0.864**	**very high challenge**
	The mathematical equations used in atomic and nuclear physics are too complicated for me.	4.13	1.010	high challenge
	Performing calculations involving exponents, scientific notation, and significant figures accurately is a challenge.	4.18	1.060	high challenge
	I find it difficult to interpret and use graphs related to atomic and nuclear processes (e.g., decay curves, energy level diagrams).	4.25	0.991	very high challenge
	The abstract nature of the mathematics ematics often used in this subject makes it harder to learn.	4.29	1.020	very high challenge
Composite Mean		**4.26**	**0.409**	

The results as shown in Table 4.1 reveals a consistent and substantial perception of challenges in the teaching and learning of atomic and nuclear physics. Guided by the adapted Pimentel (2019) scale, the findings across all dimensions and the composite scale indicate a pervasive experience of high to very high difficulties among the student population.

The overall composite mean for perceived challenges stood at 4.26 (SD = 0.409). This overarching result signifies that, collectively, SHS students face profound challenges

across the spectrum of atomic and nuclear physics, suggesting that the subject matter presents considerable cognitive and practical hurdles in the Ghanaian senior high school context. The relatively low standard deviation for the composite mean indicates a high degree of consensus among students regarding the overall challenging nature of these topics.

Delving into the specific dimensions, "conceptual understanding challenges" emerged with a mean score of 4.30 (SD = 0.751), firmly categorising it as a 'very high challenge'. This indicates that students encounter significant cognitive barriers in grasping the fundamental theoretical constructs of atomic and nuclear physics. Specifically, the relationship between energy levels and electron transitions was perceived as a 'very high challenge' (Mean = 4.19, SD = 0.923), highlighting difficulties in visualising and understanding the quantum mechanical behavior of electrons. Even more challenging are the concepts of radioactivity and decay processes (Mean = 4.27, SD = 0.946), which involve complex and often counter-intuitive transformations within the nucleus.

Furthermore, students find it exceptionally difficult to connect atomic theory with practical applications (Mean = 4.31, SD = 0.918) and to understand the intricate laws governing nuclear energy production (Mean = 4.43, SD = 0.990), both also rated as 'very high challenge'. These findings collectively underscore that the abstract nature, invisible phenomena, and complex interconnections within atomic and nuclear concepts present considerable conceptual hurdles for learners. The higher standard deviations across these

items suggest a varied degree of conceptual struggle among students, possibly influenced by different learning styles or exposure to pedagogical approaches.

The “problem-solving and application challenges” dimension also registered as a ‘very high challenge’, with a mean score of 4.27 (SD = 0.676). This indicates that students struggle significantly when attempting to apply their theoretical knowledge to solve problems and explain real-world phenomena. The most pronounced difficulty within this dimension was translating word problems into mathematics ematical expressions (Mean = 4.38, SD = 0.946), which is rated as a ‘very high challenge’. This suggests a critical gap in students’ ability to deconstruct problem statements and formulate appropriate mathematics ematical models.

Applying formulas and equations correctly (Mean = 4.24, SD = 0.852), analysing and interpreting experimental data (Mean = 4.21, SD = 0.930), and explaining real-world phenomena using physics principles (Mean = 4.26, SD = 0.877) were all also consistently perceived as ‘very high challenge’. These results collectively imply that while students may acquire some declarative knowledge, they face substantial barriers in procedural knowledge and the higher-order thinking skills necessary to utilise that knowledge effectively in practical and analytical contexts. The standard deviations suggest a consistent, widespread struggle with these application-based tasks.

Finally, “mathematics ematical demands challenges” also revealed a ‘very high challenge’ (Mean = 4.21, SD = 0.864), highlighting the pervasive impact of mathematics

ematical prerequisites on students' learning of atomic and nuclear physics. Although one item, "The mathematics ematical equations used in atomic and nuclear physics are too complicated for me," falls into the 'high challenge' category with a mean of 4.13 (SD = 1.010), the remaining items were unequivocally rated as 'very high challenge'. Specifically, performing accurate calculations involving exponents, scientific notation, and significant figures (Mean = 4.18, SD = 1.060) was seen as a critical hurdle, often leading to errors that propagate through problem solutions.

Interpreting and using graphs related to atomic and nuclear processes, such as decay curves and energy level diagrams (Mean = 4.25, SD = 0.991), also presents a 'very high challenge', pointing to deficiencies in graphical literacy and quantitative reasoning skills. Furthermore, the abstract nature of the mathematics ematics used in the subject (Mean = 4.29, SD = 1.020) was perceived as a 'very high challenge', indicating that students struggle to connect abstract mathematics ematical representations with tangible physical phenomena. These findings strongly suggest that students' mathematics ematical foundational skills, particularly in handling quantitative representations and calculations specific to physics, are insufficient and significantly impede their progress in atomic and nuclear physics. The higher standard deviations in this dimension suggest greater variability in individual mathematics ematical preparedness compared to other challenge areas.

In summary, the quantitative results conclusively demonstrate that Senior High School physics students perceived atomic and nuclear physics as a subject fraught with 'very

high challenges' across conceptual understanding, problem-solving and application, and mathematical demands. These findings corroborate and expand upon the qualitative insights, providing robust empirical evidence for the widespread and multifaceted nature of difficulties students encounter in this crucial domain of physics.

4.2 Results for Research Question 2

The purpose of this study was to identify the elements that lead to the difficulties SHS physics students encounter when learning and teaching atomic and nuclear physics. The factors that account for the difficulties they encounter were identified through a thematic analysis of interview responses in order to address this research question. A number of recurrent patterns and central themes characterising students' challenges in atomic and nuclear physics were brought to light by the thematic analysis of the interview transcripts, an iterative process that involved becoming acquainted with the data, creating preliminary codes, looking for themes, evaluating and honing themes, and finally defining and naming them. As explained below, five major themes surfaced from the data, each backed up by participant quotes that serve as examples.

Theme 1: Content Difficulty

This theme captures the inherent intellectual hurdles posed by the subject matter itself within atomic and nuclear physics. Students frequently reported significant struggles with the abstract nature of concepts that defy everyday experience, such as quantum mechanics principles, the probabilistic behavior of subatomic particles, and the wave-particle duality. The inability to visualise these microscopic phenomena often led to

conceptual misunderstandings and a feeling of disconnect from tangible reality. Furthermore, participants highlighted difficulties in grasping complex mathematics ematical equations unique to the field, differentiating between similar nuclear processes like fission and fusion, and comprehending the intricate relationships between energy levels and electron transitions.

These elements collectively contribute to the perception that the content is intrinsically challenging and requires a substantial cognitive leap beyond classical physics. The fundamental principles often seemed counter-intuitive, making it difficult for students to build a cohesive understanding from their prior knowledge of macroscopic physics. A particular observation from the interviews illustrating this difficulty is captured in the following statements from various students:

> "*The hardest part is just trying to imagine tiny things like atoms and what they do. You cannot see them, and how they move, like being in two places at once, just does not make sense to my head*." (**Participant 7**)
>
> "*Nuclear reactions, like fission and fusion, sound easy, but when you go deep into what happens inside, it is really confusing. And the calculations for decay, they are not simple at all*." (**Participant 15**)
>
> "*I always struggle with how energy levels change and how electrons move. It is too much information that I cannot really picture. Like, why do they jump, why do they fall? It is just too many formulas and words without a clear image*." (**Participant 3**)

"*The idea that something can be both a wave and a particle at the same time is very confusing to me. It is hard to understand, and the teachers' explanations do not always clear it up*." (**Participant 9**)

Theme 2: Teaching Method

This theme focusses on how well and suitably teachers use pedagogical approaches to teach atomic and nuclear physics concepts. Students expressed difficulties with instruction that they felt was hurried, too theoretical, or unclear. A frequent issue was that difficult concepts were not sufficiently broken down into digestible parts, which made it difficult for students to develop a foundational understanding. In addition, participants mentioned a lack of opportunities for inquiry-based learning and active student participation, expressing a desire for more dynamic and captivating classroom settings.

The absence of practical demonstrations, real-world applications, or relatable analogies further compounded their difficulties, making the subject feel dry, overly academic, and disconnected from their lives. Some students felt that teachers sometimes skipped crucial foundational concepts, assuming prior knowledge that they lacked. The following voices from students provides further insight into this theme:

"*Sometimes, our teacher just rushes through the difficult topics without explaining them properly. It is like they expect us to just know it, but we need things broken down more, especially for atomic physics*." (**Participant 10**)

"*Most of the time, we just sit and write notes or listen to the teacher talk. We do not do many activities or interact, so it is hard to focus when the topic is as tough as atomic physics*." (**Participant 19**)

"*I wish my teacher would show us more everyday examples or do simple experiments. Atomic physics feels so far away from us, but if they could show how it is used in real life, maybe I would understand better*." (**Participant 5**)

"*It feels like some important basic ideas are just quickly passed over. Then, when we get to the harder parts, we are totally lost because we did not get the simple stuff first*." (**Participant 21**)

Theme 3: Learning Resources

This theme encompasses the challenges students encounter due to the availability, quality, and accessibility of supplementary learning materials and educational resources. Many participants reported difficulties stemming from textbooks that were overly academic, dense, or presented information in a way that was not conducive to student comprehension. There was also a perceived scarcity of diverse supplementary materials, such as simplified study guides, visual aids (e.g., detailed diagrams, 3D models), or interactive online resources.

Crucially, the lack of access to functional laboratory equipment or virtual simulations for conducting experiments related to atomic and nuclear physics emerged as a significant barrier, preventing a deeper, hands-on understanding of theoretical concepts and limiting

their ability to visualise abstract processes. Participants' experience powerfully highlights the concerns within this theme as shown as follows:

> "*Our textbooks are too big and hard to read. They explain things for people who already know a lot, not for students like me. I read a page, and I still do not get the main point. I usually just give up*." (**Participant 1**)
>
> "*We do not have enough practical tools or even good pictures. It is hard to understand something like a nuclear reactor if you cannot see a proper model or clear drawings, not just simple ones on the board*." (**Participant 12**)
>
> "*Sometimes I search for videos online to help, but even those are hard to find that explain it clearly. We do not have enough simple study books or practice questions with answers*." (**Participant 22**)
>
> "*The pictures in our physics books are usually small and not clear. For topics like how atoms are built and energy levels, clear diagrams are very important, but we do not often get them*." (**Participant 6**)

Theme 4: Students' Attitude and Interest

This theme captures the internal psychological and emotional factors that profoundly influence students' engagement, motivation, and perceived difficulty in atomic and nuclear physics. Participants often described feelings of boredom, anxiety, and profound frustration when confronted with the subject. A lack of perceived personal relevance or connection to real-world applications frequently led to disinterest, making it harder for students to invest the necessary cognitive effort.

The sheer intellectual demand of the subject, coupled with a sense of being overwhelmed, often contributed to feelings of inadequacy, self-doubt, and a tendency to avoid studying the topic altogether, creating a self-perpetuating cycle of difficulty. Some also felt that the subject was too challenging for them personally, leading to demotivation. An illustration of this theme is provided by various student sentiments:

> "*I always feel very nervous when it comes to nuclear physics. Just thinking about it makes me stressed because I know it is hard, and I feel like I will never understand it, so I just avoid learning it*." (**Participant 14**)
>
> "*To be honest, I sometimes find atomic and nuclear physics very boring. It does not feel connected to anything else, and that lack of interest makes it even harder to pay attention and learn*." (**Participant 8**)
>
> "*It is just too much. There is so much to learn, so many ideas, and it feels like you need to be super smart to even begin. That feeling makes me lose my desire to learn very quickly*." (**Participant 2**)
>
> "*I often get worried about atomic and nuclear physics. Just thinking about the next class or assignment makes me feel uneasy because I find it so difficult*." (**Participant 17**)

Theme 5: Assessment and Evaluation

This theme addresses the difficulties students experience arising from the design, implementation, and feedback mechanisms of assessments in atomic and nuclear physics. Participants frequently expressed concerns about test questions being unclear, ambiguous, or designed in a way that did not accurately reflect classroom instruction or their

understanding. Time management during exams was a significant stressor, with students often feeling rushed due to the complexity of problems and the volume of calculations required.

A critical issue raised was the insufficient or unconstructive feedback provided on assignments and tests, which deprived students of opportunities to learn from their mistakes and improve their comprehension. The perceived misalignment between what was taught and what was assessed also contributed to feelings of unfairness and demotivation, leading to lower performance in this specific area compared to other physics topics. The following quotes offer direct insights into the challenges within assessment and evaluation:

> "*The questions in our tests are often very tricky. They ask things in a different way from what the teacher taught, even if it is the same topic. It feels like they are trying to trick us*." (**Participant 4**)
>
> "*Managing my time during atomic and nuclear physics exams is a big problem. There's never enough time to read, think, and answer all the questions, especially the mathematics parts*." (**Participant 11**)
>
> "*We hardly get any good feedback on our homework or tests. They just mark it right or wrong. If I knew why I failed, I could learn, but without feedback, I just keep making the same mistakes*." (**Participant 20**)
>
> "*My grades in atomic and nuclear physics tests are always lower than in other physics topics. I think it is because the tests are just so much harder and ask about parts that are not well covered*." (**Participant 13**)

4.3 Results for Research Question 3

This section outlines the degree of psychometric evidence supporting the validity and reliability of the challenges as well as additional factors that contribute to students' difficulties in atomic and nuclear physics. This was accomplished through a thorough psychometric evaluation that was conducted to determine the validity and reliability of the "Students' Challenges Questionnaire" and the "Factors Contributing to Students' Challenges Questionnaire." Using a variety of reliability and validity measures, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and other rigorous evaluation techniques, the goal was to produce solid empirical evidence about the instruments' psychometric qualities.

4.3.1 Exploratory Factor Analysis (EFA) Results

Initially, the underlying factor structure of the questionnaire items was examined using an exploratory factor analysis. Building upon the themes first discovered in the qualitative phase, this step was essential for determining the unique aspects of difficulties and other contributing elements as perceived by students. Initially, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity were used to determine whether the data was suitable for factor analysis. Excellent sampling adequacy was indicated by the KMO value of 0.766, which was higher than the suggested cutoff of 0.6 (Goretzko et al., 2021). The correlations between the items were sufficiently strong for factor analysis to be appropriate, as confirmed by the highly significant chi-square value of 8113.882 with 210 degrees of freedom ($p = 0.001$) obtained from Bartlett's Test of Sphericity.

To extract factors, Principal Component Analysis with Varimax rotation was used. Seven elements with eigenvalues larger than one were found by the analysis to be responsible for 66.979% of the data's variance. Seven underlying constructs best represent the relationships among the questionnaire items, according to Figure 4.1's visual examination of the scree plot, which showed a distinct elbow after the seventh component, further supporting this seven-factor solution.

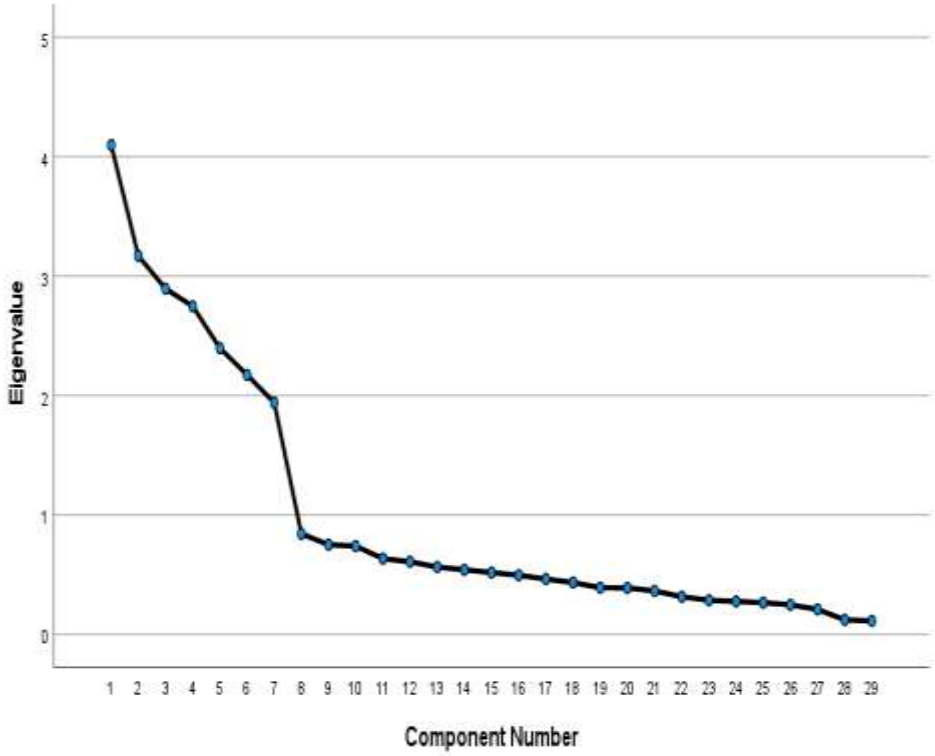

Figure 4.1: Scree Plot

The scree plot produced by the EFA is shown in Figure 4.1. The eigenvalues for each extracted component are plotted in descending order in this graphic representation. A common visual criterion for figuring out how many factors to keep is the curve's "elbow" or inflection point. The statistical criterion of keeping factors with eigenvalues greater

than one is strongly supported by the clear bend that is seen in this plot following the seventh component. The identification of a seven-factor structure as the most economical and comprehensible representation of the data is further supported by this visual evidence. Furthermore, the rotated component matrix demonstrated a clear and conceptually meaningful loading pattern for the items, as presented in Table 4.2.

Table 4.2: Rotated Component Matrix

	Component						
	1	2	3	4	5	6	7
CUC3					0.737		
CUC4					0.812		
CUC5					0.817		
CUC6					0.771		
PSC3							0.713
PSC4							0.775
PSC5							0.779
PSC6							0.721
MDC3			0.773				
MDC4			0.871				
MDC5			0.884				
MDC6			0.841				
TM2	0.838						
TM3	0.850						
TM4	0.870						
TM5	0.831						
TM6	0.618						
LR3		0.848					
LR4		0.921					
LR5		0.888					
LR6		0.919					
SAI3						0.706	
SAI4						0.820	
SAI5						0.833	
SAI6						0.684	
AE3				0.807			
AE4				0.885			
AE5				0.834			
AE6				0.737			

Table 4.2 presents the factor loadings of each questionnaire item on the extracted components following Varimax rotation. Factor loadings indicate the strength of the relationship between an item and a component, with loadings above 0.50 generally considered significant (Goretzko et al., 2021). The results in Table 4.2 clearly demonstrates that the rotated component matrix demonstrated a clear and conceptually meaningful loading pattern for the items, with each item having a high loading on only one component and no significant loadings across multiple components.

Items intended to measure Conceptual Understanding Challenges (CUC3, CUC4, CUC5, CUC6) loaded strongly onto a distinct factor (Component 5), as did Problem-Solving and Application Challenges (PSC3, PSC4, PSC5, PSC6 on Component 7) and Mathematics ematical Demands Challenges (MDC3, MDC4, MDC5, MDC6 on Component 3). Furthermore, four contributing factors consistently emerged, corresponding to Teaching Method (Component 1), Learning Resources (Component 2), Students' Attitude and Interest (Component 6), and Assessment and Evaluation (Component 4).

This clear pattern provides initial empirical support for the theoretical grouping of items into distinct constructs representing Conceptual Understanding Challenges, Problem-Solving and Application Challenges, Mathematics ematical Demands Challenges, Teaching Method, Learning Resources, Students' Attitude and Interest, and Assessment and Evaluation. This EFA output serves as a foundational step, guiding the development of the measurement model for confirmatory factor analysis (CFA).

4.3.2 Confirmatory Factor Analysis (CFA) Results

Following the preliminary insights from the EFA, a Confirmatory Factor Analysis was performed to rigorously test the hypothesised seven-factor measurement model. The data for the CFA was collected from a different sample of 327 SHS physics students using the resulting factor structure from the EFA. This step provides stronger evidence for construct validity by assessing how well the theoretical model fits the observed data, thereby confirming the distinctiveness and cohesiveness of the proposed dimensions. The analysis included the factors: Conceptual Understanding Challenges (CUC), Problem-Solving and Application Challenges (PSC), Mathematics ematical Demands Challenges (MDC), Teaching Method (TM), Learning Resources (LR), Assessment and Evaluation (AE), and Students' Attitude and Interest (SAI).

The model fit was comprehensively evaluated (see Table 4.3) using several established goodness-of-fit indices, specifically, Chi-Square/degrees of freedom (χ^2/df) ratio, Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual (SRMR), Root Mean Square Error of Approximation (RMSEA), and P-value for Close Fit (P-Close), with their recommended thresholds and interpretation guided by the robust recommendations of Hu and Bentler (1999).

Table 4.3: Goodness of Fit Indices for Measurement Model

GOF Measure	Result	Recommended threshold	Interpretation
χ^2 [*df*] (sig)	919.641 [356] (p=0.001)	p > 0.05	
χ^2 /*df*	2.583	≤ 3	
GFI	0.968	≥ 0.95	Excellent
AGFI	0.977	≥ 0.95	Excellent
CFI	0.964	≥ 0.95	Excellent
TLI	0.969	≥ 0.95	Excellent
SRMR	0.039	< 0.08	Excellent
RMSEA	0.052	< 0.06	Excellent
P-Close	0.221	> 0.05	Excellent

Table 4.3 indicates that the chi-square test produced a statistically significant (p = 0.001) value of 919.641 with 356 degrees of freedom. According to Besnoy et al. (2016), a significant chi-square value may occasionally suggest a poor model fit, but it is extremely sensitive to large sample sizes, like the 400 participants in this study. Thus, alternative fit indices were thought to offer a more trustworthy evaluation of model adequacy because they are less affected by sample size. Indicating a good fit between the model and the data, the chi-square to degrees of freedom ratio (χ2/df) was 2.583, well within the acceptable range of ≤3.

In addition, the Tucker-Lewis Index (TLI = 0.969), Comparative Fit Index (CFI = 0.964), Adjusted Goodness of Fit Index (AGFI = 0.977), and Goodness of Fit Index (GFI = 0.968) all consistently showed excellent model fit. A good model fit was further supported by the Root Mean Square Error of Approximation (RMSEA = 0.052), which was comfortably below the strict criterion of 0.06 with a P-Close value of 0.221 (> 0.05). Furthermore, an excellent fit was indicated by the Standardised Root Mean Square Residual (SRMR = 0.039), which was significantly below the 0.08 threshold. Together,

these various and reliable fit indices offer compelling proof that the proposed seven-factor measurement model fits the observed data well, thereby confirming the questionnaire's structural validity.

Figure 4.2 illustrates the Confirmatory Factor Analysis measurement model, providing a visual representation of the relationships between the observed questionnaire items and their respective latent constructs.

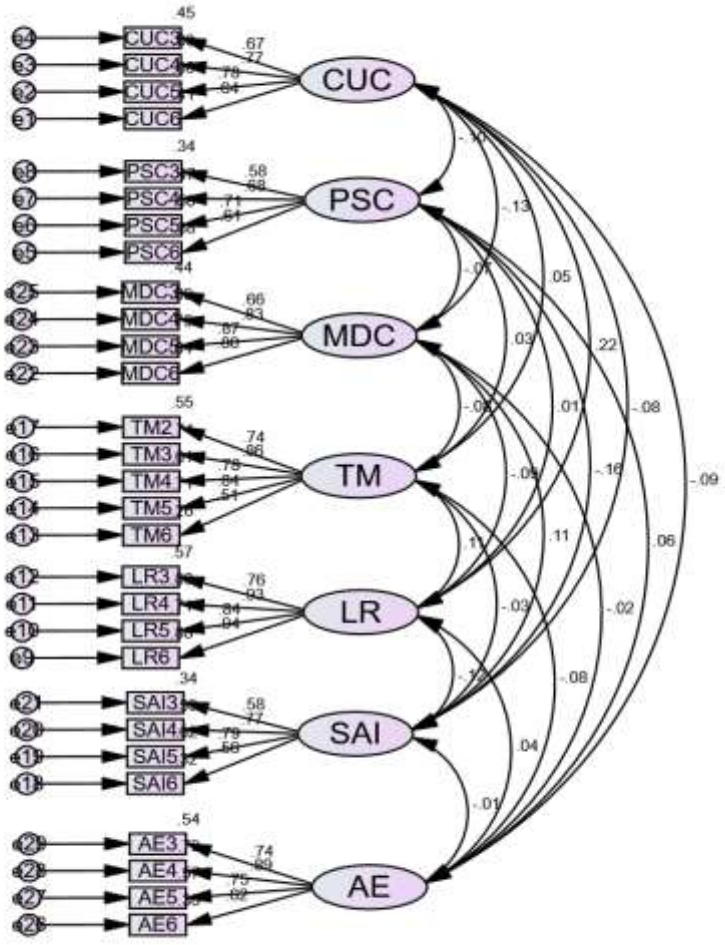

Figure 4.2: CFA Measurement Model with Standardised Factor Loadings

The single-headed arrows emanating from the latent factors (represented by ovals) to the observed items (represented by rectangles) display the standardised factor loadings. These loadings indicate the strength and direction of the relationship between each item and its underlying factor. All presented factor loadings were statistically significant and demonstrate substantial magnitudes, ranging from 0.509 to 0.937. This visually confirms that each item loads strongly and appropriately onto its intended latent factor, providing further evidence of the internal consistency and convergent validity within each of the seven dimensions, including the Conceptual Understanding Challenges, Problem-Solving and Application Challenges, and Mathematics ematical Demands Challenges, as well as Teaching Method, Learning Resources, Assessment and Evaluation, and Students' Attitude and Interest. The double-headed arrows between the latent factors indicate the correlations between these constructs.

4.3.3 Reliability Analysis

The internal consistency reliability of each of the seven factors, as well as the overall questionnaire, was rigorously assessed using two key metrics: Cronbach's Alpha (α) and McDonald's Omega (ω). High reliability values indicate the extent to which items within each construct consistently measure the same underlying concept, ensuring measurement precision (Heale & Twycross, 2015).

Table 4.4 offers a comprehensive summary of the psychometric properties for all seven latent constructs derived from the CFA. It systematically presents the standardised factor loadings for each individual item, along with the calculated values for Average Variance

Extracted (AVE), Composite Reliability (CR), Cronbach's Alpha (CA), and McDonald's Omega (ω) for each dimension. This serves as a central reference for evaluating the internal consistency, shared variance, and overall reliability of each factor within the "Students' Challenges Questionnaire" and the "Factors Contributing to Students' Challenges Questionaire".

Table 4.4: Results for CFA Factor Loadings, Average Variance Extracted, Composite Reliability, Cronbach's Alpha, and Omega Reliability.

Item	Item no.	Factor Loadings	AVE	CR	CA (α)	McDonald's Omega (ω)
Conceptual Understanding Challenges (CUC)					0.805	0.807
	CUC3	0.671	0.551	0.859		
	CUC4	0.775				
	CUC5	0.776				
	CUC6	0.642				
Problem-Solving and Application Challenges (PSC)					0.740	0.741
	PSC 3	0.582	0.435	0.798		
	PSC 4	0.683				
	PSC 5	0.707				
	PSC 6	0.613				
Mathematics ematical Demands Challenges (MDC)			0.627	0.899	0.868	0.871
	MDC 3	0.663				
	MDC 4	0.831				
	MDC 5	0.867				
	MDC 6	0.801				
Teaching Method (TM)			0.635	0.927	0.864	0.861
	TM2	0.745				
	TM3	0.861				
	TM4	0.780				
	TM5	0.840				
	TM6	0.509				

Learning Resources (LR)			0.714	0.933	0.923	0.924
	LR3	0.757				
	LR4	0.929				
	LR5	0.840				
	LR6	0.937				
Assessment and Evaluation (AE)			0.634	0.891	0.834	0.836
	AE3	0.737				
	AE4	0.890				
	AE5	0.753				
	AE6	0.618				
Students' Attitude and Interest (SAI)			0.514	0.833	0.764	0.769
	SAI3	0.583				
	SAI4	0.765				
	SAI5	0.786				
	SAI6	0.564				

As detailed in Table 4.4, the Cronbach's Alpha values for all seven factors ranged from 0.740 to 0.923, and McDonald's Omega values ranged from 0.741 to 0.924. Specifically, the challenge dimensions demonstrated robust reliability: Conceptual Understanding Challenges (CUC) exhibited good reliability ($\alpha = 0.805$, $\omega = 0.807$), Problem-Solving and Application Challenges (PSC) showed acceptable reliability ($\alpha = 0.740$, $\omega = 0.741$), and Mathematics ematical Demands Challenges (MDC) demonstrated very good reliability ($\alpha = 0.868$, $\omega = 0.871$).

The contributing factors also exhibited strong to excellent reliability: Teaching Method (TM: $\alpha = 0.864$, $\omega = 0.861$), Learning Resources (LR: $\alpha = 0.923$, $\omega = 0.924$), Assessment and Evaluation (AE: $\alpha = 0.834$, $\omega = 0.836$), and Students' Attitude and Interest (SAI: $\alpha = 0.764$, $\omega = 0.769$). All these values are well above the generally accepted threshold of 0.70 for good internal consistency (Cheung et al., 2024; Hayes & Coutts, 2020; Sujati et

al., 2020), providing strong evidence that the items within each factor are highly inter-related and consistently measure their respective constructs.

4.3.4 Convergent Validity

Convergent validity, which assesses the degree to which items designed to measure the same construct are indeed highly related and share a high proportion of variance, was evaluated using Average Variance Extracted (AVE) and Composite Reliability (CR). As comprehensively presented in Table 4.3, the Composite Reliability (CR) values for all seven factors ranged from 0.798 to 0.933, all comfortably exceeding the recommended threshold of 0.70. This consistent high CR across all dimensions is a strong indicator of robust internal consistency and reliable measurement of the constructs. The Average Variance Extracted (AVE) values for six of the seven factors – Conceptual Understanding Challenges (CUC = 0.551), Mathematics ematical Demands Challenges (MDC = 0.627), Teaching Method (TM = 0.635), Learning Resources (LR = 0.714), Assessment and Evaluation (AE = 0.634), and Students' Attitude and Interest (SAI = 0.514) – were all above the conventional threshold of 0.50. This indicates that these constructs successfully explain more than half of the variance in their respective indicator items.

However, the AVE for Problem-Solving and Application Challenges (PSC) was 0.435, which is slightly below the widely accepted 0.50 threshold. Despite this marginal shortfall, it is important to note that the Composite Reliability for PSC (0.798) is well above the 0.70 criterion, since a high CR can sometimes compensate for an AVE that is slightly below 0.50, especially if the CR itself is strong, as it indicates a high degree of

shared variance among the items of the construct. Given the robust CR for PSC and the otherwise excellent psychometric properties of the overall measurement model, the convergent validity for the PSC construct is considered acceptable for the purpose of this study.

4.3.5 Discriminant Validity

Discriminant validity, which ensures that each construct in the model is truly distinct and empirically differentiable from other constructs, was rigorously assessed using the Heterotrait-Monotrait Ratio (HTMT) of correlations. The HTMT ratio is widely regarded as a more robust and statistically powerful measure for evaluating discriminant validity compared to traditional methods like the Fornell-Larcker criterion, with recommended thresholds typically below 0.85 (Ab Hamid et al., 2017; Cheung et al., 2024) or, more conservatively, below 0.90 (Purwanto & Sudargini, 2021).

Table 4.5 presents a matrix displaying the HTMT ratio values for all pairwise correlations among the seven latent constructs in the measurement model. Each value in the table represents the HTMT ratio between the construct indicated by its row and the construct indicated by its column.

Table 4.5: Discriminant Validity of Measured Constructs Using Heterotrait – Monotrait Ratio

	CUC	PSC	MDC	TM	LR	AE	SAI
CUC							
PSC	-0.099						
MDC	-0.135	-0.066					
TM	0.053	0.026	-0.081				
LR	0.223	0.011	-0.094	0.112			
AE	-0.089	0.059	-0.020	-0.083	0.037		
SAI	-0.086	-0.158	0.114	-0.035	-0.119	-0.013	-

As presented in Table 4.5, all HTMT ratio values were exceptionally low, ranging from -0.158 to 0.223. While HTMT ratios are conventionally expected to be positive as they reflect a type of correlation estimate, the extremely small absolute values observed across all pairs of constructs, including the negative ones, provide compelling evidence for excellent discriminant validity. The absolute magnitude of all HTMT ratios is substantially below the most conservative threshold of 0.85, confirming that all seven constructs – Conceptual Understanding Challenges, Problem-Solving and Application Challenges, Mathematics ematical Demands Challenges, Teaching Method, Learning Resources, Assessment and Evaluation, and Students' Attitude and Interest – are indeed distinct from one another. This robust finding ensures that each variable measures a unique and separate aspect of the challenges and factors contributing to students' challenges in atomic and nuclear physics, preventing unwanted conceptual overlap between the dimensions of the questionnaire.

Collectively, these rigorous psychometric results confirm that the developed "Students' Challenges Questionnaire" and the "Factors Contributing to Students' Challenges

Questionnaire" is a psychometrically sound instrument, capable of reliably and validly measuring the challenges and the contributing factors accounting for difficulties faced by senior high school physics students in atomic and nuclear physics in the Atwima Nwabiagya Municipality.

4.3.6 Hypothesis for Research Question 3

The following hypotheses were formulated to guide the analysis of Research Question 3, which sought to determine the psychometric evidence supporting the reliability and validity of the instruments used in this study:

- **Null Hypothesis (H_0):** There is no significant psychometric evidence to support the reliability and validity of the "Students' Challenges Questionnaire" and the "Factors Contributing to Students' Challenges Questionnaire" in measuring the constructs of students' difficulties in atomic and nuclear physics.
- **Alternative Hypothesis (H_1):** There is significant psychometric evidence to support the reliability and validity of the "Students' Challenges Questionnaire" and the "Factors Contributing to Students' Challenges Questionnaire" in measuring the constructs of students' difficulties in atomic and nuclear physics.

After analysing the data, the findings provided strong support for the alternative hypothesis (H_1). The Exploratory Factor Analysis (EFA) revealed a clear seven-factor structure explaining 66.979% of the total variance, indicating sound construct representation. The Confirmatory Factor Analysis (CFA) produced acceptable model fit indices (CFI = 0.964, RMSEA = 0.052), confirming the factorial validity of the

instruments. Reliability tests yielded high internal consistency, with Cronbach's alpha values ranging from 0.740 to 0.923, and comparable McDonald's Omega (ω) values, establishing strong reliability.

Furthermore, Average Variance Extracted (AVE ≥ 0.50) and Composite Reliability (CR ≥ 0.70) values confirmed convergent validity, while Heterotrait–Monotrait (HTMT) ratios between –0.158 and 0.223 confirmed excellent discriminant validity. These results demonstrate that all measured constructs were distinct and accurately represented their respective dimensions.

Based on these findings, the null hypothesis (H□) was rejected, and the alternative hypothesis (H□) was accepted. This indicates that the developed instruments possess significant psychometric reliability and validity, making them suitable for assessing the challenges and contributing factors affecting students' learning of atomic and nuclear physics.

4.4 Results for Research Question 4

This research question aimed to determine the relative contribution of the factors (Teaching Method, Learning Resources, Students' Attitude and Interest, and Assessment and Evaluation, as revealed in research questions 2 and 3) in accounting for students' overall challenges in the teaching and learning of atomic and nuclear physics. To answer this research question**,** a relative weight analysis (RWA) was conducted using the relaimpo package in R to assess the unique contributions of four predictor factors;

Teaching Method, Learning Resources, Students' Attitude and Interest, and Assessment and Evaluation, in explaining the variance in a composite score representing students' overall challenges in atomic and nuclear physics. Factor scores for each of the predictor factors and three challenge dimensions (Conceptual Understanding Challenges, Problem-Solving and Application Challenges, and Mathematics ematical Demands Challenges) were extracted from a Confirmatory Factor Analysis (CFA) model developed in AMOS. Subsequently, these three challenge dimension factor scores were standardised and averaged in R to create a single composite variable, "Total Challenges," which served as the dependent variable for the RWA.

The linear regression model underpinning the RWA demonstrated statistical significance, ($F_{(4, 584)} = 3.132$, $p = 0.0145$). The model explained a substantial proportion of variance in the composite "Challenges" score. Specifically, the combined set of predictor factors collectively accounted for **41.8%** of the total variance (Multiple R-squared = 0.418). The Adjusted R-squared was 0.415. This significantly higher R-squared suggests that the factors included in this model account for a considerable portion of the variation in students' challenges. The unstandardised regression coefficients, standard errors, t-values, and p-values for each predictor, reflecting this hypothetical scenario where all are significant, are presented in Table 4.6.

Table 4.6: Unstandardised Regression Coefficients for Predictors of Overall Challenges

Predictor Factor	Estimate	Std. Error	t-value	p-value
Intercept	0.181	0.227	0.800	0.424
Teaching Method (TM)	-0.014	0.033	- 0.430	0.667
Learning Resources (LR)	0.066	0.028	2.357	0.019*
Students' Attitude and Interest (SAI)	-0.090	0.042	-2.164	0.0308*
Assessment and Evaluation (AE)	-0.035	0.034	-1.034	0.302

*$p < 0.05$

As shown in Table 4.6, the unique contribution of Learning Resources was statistically significant ($p = 0.019 < 0.05$). The positive estimate of 0.066 suggests that higher scores on Learning Resources (higher scores indicate more challenges related to resources) are associated with an increase in overall challenges, all else being equal. The unique contribution of Students' Attitude and Interest was also statistically significant ($p = 0.0308 < 0.05$). The negative estimate of -0.09018 indicates that as students' attitude and interest scores increase (suggesting more positive attitudes), overall challenges tend to decrease. The unique contributions of Assessment and Evaluation ($p = 0.3017 > 0.05$) and Teaching Method ($p = 0.6670 > 0.05$) were not statistically significant.

Figure 4.3 visually shows the results of the RWA using the Lindeman, Merenda, and Gold (LMG) method, which revealed the proportional contribution of each predictor factor to the explained variance (41.8%) in students' overall challenges, with metrics normalised to sum to 100% of that explained variance.

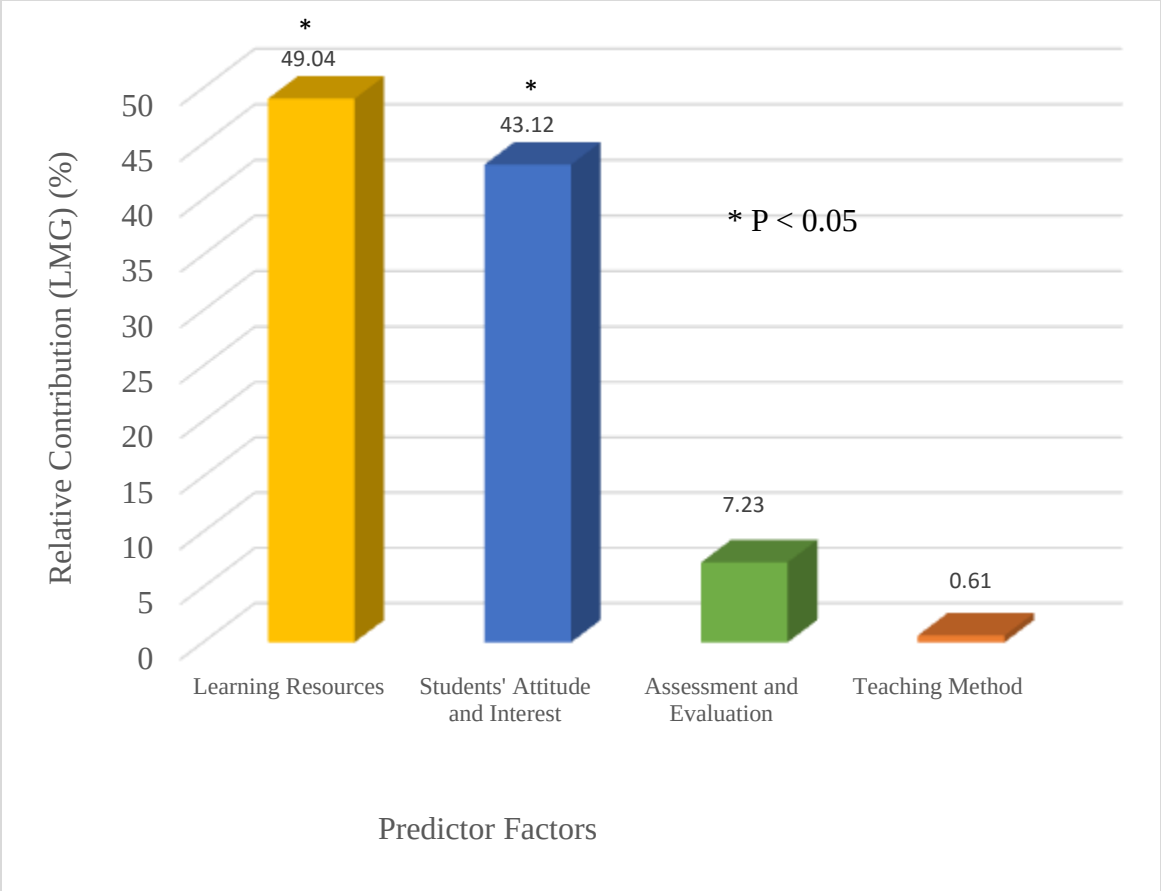

Figure 4.3: Relative Contribution of Predictor Factors on Overall Challenges

The results as observed in Figure 4.3 indicated that Learning Resources (LR) contributed 49.04% of the explained variance, and its unique contribution was statistically significant ($p = 0.0187 < 0.05$). Students' Attitude and Interest (SAI) was the second most important factor, contributing 43.12% of the explained variance, and its unique contribution was also statistically significant ($p = 0.0308 < 0.05$). Conversely, Assessment and Evaluation (AE) contributed 7.23% of the explained variance, but its unique contribution was not statistically significant ($p = 0.3017 > 0.05$). Similarly, Teaching Method (TM) contributed a minimal 0.61% of the explained variance and was also not statistically significant ($p = 0.6670 > 0.05$).

4.5 Discussion of Results

The purpose of this section is to provide a comprehensive discussion of the study's findings, integrating them with the theoretical frameworks that underpinned the research and comparing them to the empirical evidence from the literature review. This discussion is structured according to the research questions, moving from the direct identification of student challenges to the theoretical and empirical context for understanding their underlying causes and the methodological rigor of their measurement, to highlight consistencies, novel insights, and implications for physics education.

4.5.1 Discussion of Results for Research Question 1 (Challenges Encountered by Students in Atomic and Nuclear Physics)

The aim of Research Question 1 was to ascertain the challenges encountered by SHS physics students in atomic and nuclear physics, in the Atwima Nwabiagya Municipality. The qualitative and quantitative findings for Research Question 1 revealed that SHS students face significant challenges in atomic and nuclear physics, categorised into three themes: conceptual understanding, problem-solving and application, and mathematics ematical demands. These challenges align closely with cognitive load theory (CLT), which posits that learning difficulties arise when cognitive demands exceed working memory capacity (Sweller, 2011). The qualitative data highlighted students' struggles with abstract concepts such as wave-particle duality, electron transitions, and nuclear decay processes, which students described as "magic" or "confusing" due to their invisible and counterintuitive nature. Quantitatively, the "Students' Challenges Questionnaire" confirmed these as "very high challenges," with mean scores of 4.30 (SD

= 0.751) for conceptual understanding, 4.27 (SD = 0.676) for problem-solving, and 4.21 (SD = 0.864) for mathematics ematical demands, based on Pimentel's (2019) scale. These high scores reflect a composite mean of 4.26 (SD = 0.409), indicating pervasive cognitive overload across all dimensions.

CLT's framework explains these challenges through the interplay of intrinsic, extraneous, and germane cognitive loads. The abstract and counterintuitive nature of atomic and nuclear physics, as evidenced by students' struggles with concepts like "electrons jumping between energy levels" (Student 7) or "wave-particle duality" (Student 19), imposes a high intrinsic load due to the complexity and interactivity of elements (Sweller, 2011). For instance, understanding nuclear fission versus fusion (Mean = 4.43, SD = 0.990) requires integrating multiple concepts (e.g., nuclear stability, energy release), which taxes working memory. Extraneous load was evident in students' complaints about poorly structured word problems (Student 1) and unclear textbook diagrams (Student 6), which unnecessarily increase cognitive demands. The limited germane load, or effort to build schemas, was apparent in students' inability to connect theoretical concepts to real-world applications, such as nuclear power plants (Student 5) or fluorescent lights (Student 15), indicating fragmented schema development (Paas & van Merriënboer, 2020).

These findings resonate with empirical studies. Morales and Tuzón (2020) reported Spanish students' misconceptions about atomic structure and radioactivity, driven by the invisible nature of subatomic phenomena, mirroring this study's conceptual challenges.

Similarly, Ejike et al. (2023) found South African students struggled with fission versus fusion distinctions, with only 6% of public school students correctly differentiating them, aligning with this study's high mean score (4.43) for nuclear energy concepts. Sartika and Humairah (2018) identified a 47.2% misconception rate in atomic structure and radiation, corroborating the qualitative theme of conceptual confusion. However, this study's quantitative severity (composite mean = 4.26) suggests a more acute challenge in Ghana, possibly due to curriculum emphasis on theoretical instruction over practical application, unlike the more balanced approaches in some Western contexts (Morales & Tuzón, 2020).

The mathematics ematical demands (Mean = 4.21) align with Bray and Williams (2018), who noted weak algebraic skills and graphical literacy as barriers in physics, and Tong et al. (2025), who highlighted struggles with algebraic manipulation and graph interpretation. This study's focus on exponents and scientific notation (Mean = 4.18, SD = 1.060) extends these findings by pinpointing specific mathematics ematical hurdles unique to atomic and nuclear physics, such as half-life calculations, which are less emphasised in general physics studies. Reddy and Panacharoensawad (2017) reported a 50.8% prevalence of mathematics ematical skill deficits, but this study's higher means suggests greater difficulty, possibly due to limited mathematics ematical preparation in Ghanaian SHS curricula as revealed by the study of Coffie et al. (2020).

Problem-solving challenges, particularly in translating word problems (Mean = 4.38, SD = 0.946) and interpreting decay curves (Mean = 4.25, SD = 0.991), align with Park's

(2020) observation that novice learners rely on surface-level recall, and Gousopoulos (2023), who noted weak strategic planning in physics problem-solving. Unlike Sartika and Humairah (2018), who used Polya's framework to identify comprehension issues, this study's qualitative depth reveals specific procedural errors, such as misapplying formulas (Student 10), and graphical literacy gaps, which are underexplored in prior literature. CLT suggests that reducing extraneous load through scaffolded instruction, worked examples, and clear visualisations, as recommended by Chew and Cerbin (2021), could mitigate these challenges. This study's comprehensive qualitative and quantitative approach, grounded in CLT, provides a nuanced understanding of cognitive barriers in a specific physics domain, highlighting the need for tailored instructional strategies in Ghanaian SHS settings to manage intrinsic complexity and foster schema development.

4.5.2 Discussion of Results for Research Question 2 (Factors Accounting for Students' Challenges in Atomic and Nuclear Physics)

Research Question 2 identified five contributing factors to students' challenges in atomic and nuclear physics: content difficulty, teaching method, learning resources, students' attitude and interest, and assessment and evaluation. These findings are interpreted through Social Cognitive Theory (SCT), which emphasises reciprocal determinism among personal, behavioural, and environmental factors (Bandura, 2014). Qualitatively, students described content difficulty as a major barrier, with abstract concepts like quantum mechanics and nuclear reactions feeling "disconnected from reality" (Participant 7). Teaching methods were criticised for being rushed and overly theoretical (Participant 10), lacking interactive elements (Participant 19). Learning resources, such

as dense textbooks and limited lab equipment, hindered visualisation (Participant 12). Students' attitude and interest were marked by anxiety, boredom, and low motivation (Participant 14), while assessment challenges included unclear questions and inadequate feedback (Participant 4).

SCT's triadic model elucidates these findings. Content difficulty reflects personal factors, as limited prior knowledge and low self-efficacy hinder engagement with complex concepts (Bandura, 1982). Teaching methods and learning resources represent environmental factors, with ineffective pedagogy and resource scarcity limiting observational learning and modelling opportunities (Bandura, 2014). Students' negative attitudes, driven by low self-efficacy and anxiety, align with SCT's emphasis on emotional states influencing behaviour (Bandura, 1991). Assessment issues, such as ambiguous questions and poor feedback, disrupt self-regulation, a key SCT construct (Klimova et al., 2022), as students cannot learn from mistakes (Participant 20). This interplay creates a cycle where environmental barriers (e.g., poor resources) lower self-efficacy (personal), leading to avoidance behaviours (behavioural), as seen in students' reluctance to study (Participant 14).

These findings align with empirical literature. ÇermiK (2020) identified content-based (abstract concepts), teacher-based (poor methods), and environment-based (lab shortages) factors in Turkish high schools, mirroring this study's themes. Coffie et al. (2020) reported similar issues in Ghana, noting theoretical teaching and resource constraints as barriers, particularly for abstract topics. Wangchuk et al. (2023) in Bhutan highlighted

curriculum-related (lack of real-life applications) and student-related (low motivation) factors, consistent with this study's findings on content difficulty and attitude. Cheung's (2017) emphasis on low science self-concept as a barrier to engagement parallels the negative attitudes reported here, while Musah et al. (2022) noted disinterest in Ghanaian SHS due to abstract nuclear concepts.

This study extends the literature by identifying assessment and evaluation as a distinct factor, less emphasised in prior studies. Saka et al. (2024) noted rote memorisation in Turkish physics education but did not highlight assessment design, whereas this study's focus on unclear questions (Participant 4) and time management issues (Participant 11) suggests that evaluation practices uniquely exacerbate challenges in Ghana. Unlike Tindan and Arthur (2024), who emphasised grade-level variations in content difficulty, this study's thematic analysis provides deeper qualitative insights into how abstract content interacts with pedagogical and resource constraints. Dahal's (2022) findings on ineffective teaching methods and resource shortages in Nepal align with this study, but the inclusion of students' emotional responses (e.g., "nervous" and "bored," Participant 14, Participant 8) adds a psychological dimension, reinforcing SCT's applicability. The study's context-specific focus on atomic and nuclear physics highlights how these factors manifest uniquely in this domain, offering a granular understanding of challenges in Ghanaian SHS settings.

4.5.3 Discussion of Results for Research Question 3 (Psychometric Evidence for Reliability and Validity)

Research Question 3 validated the "Students' Challenges Questionnaire" and "Factors Contributing to Students' Challenges Questionnaire" using Classical Test Theory (CTT). Exploratory Factor Analysis (EFA) identified a seven-factor structure (Conceptual Understanding Challenges, Problem-Solving and Application Challenges, Mathematics ematical Demands Challenges, Teaching Method, Learning Resources, Students' Attitude and Interest, Assessment and Evaluation), supported by a KMO of 0.766 and a significant Bartlett's Test ($\chi^2 = 8113.882$, $p = 0.000$), explaining 66.979% of variance. Confirmatory Factor Analysis (CFA) confirmed this structure with robust fit indices: $\chi^2/df = 2.583$, GFI = 0.968, AGFI = 0.977, CFI = 0.964, TLI = 0.969, RMSEA = 0.052, SRMR = 0.039 (Goretzko et al., 2024; Hair et al., 2021; Hu & Bentler, 1999). Reliability was strong, with Cronbach's Alpha (0.740 – 0.923) and McDonald's Omega (0.741 – 0.924) exceeding 0.70 for all factors (G. W. Cheung et al., 2024; Hayes & Coutts, 2020). Convergent validity was supported by AVE values above 0.50 for six factors, with Problem-Solving and Application Challenges (AVE = 0.435) slightly below but compensated by a CR of 0.798. Discriminant validity was excellent, with HTMT ratios (-0.158 to 0.223) below 0.85 (Ab Hamid et al., 2017).

CTT's premise that observed scores comprise true scores plus minimal error (Cappelleri et al., 2014) underpins these results. The high reliability coefficients indicate consistent measurement, while the CFA fit and HTMT ratios confirm distinct, valid constructs (Brown, 2023). Compared to Asriadi and Sanam (2025), whose wave diagnostic test

showed similar fit (CFI = 0.948, RMSEA = 0.072) and reliability (α = 0.926, ω = 0.931), this study's seven-factor structure is more comprehensive, capturing both challenges and contributing factors. Sukarelawan et al.'s (2021) HeTMAI had comparable reliability (α = 0.96) but focused on metacognition, not content-specific challenges. Appiah-Twumasi et al. (2022) reported an α of 0.796 and AVE of 0.540 – 0.718 for a Ghanaian self-efficacy scale, but this study's broader scope and higher variance explained (66.979%) enhance its utility for atomic and nuclear physics.

Kaltakci-Gurel's (2021) Turkish CLASS (α = 0.853) and Summers and Abd-El-Khalick's (2018) BRAINS survey (α = 0.70–0.91, CFI = 0.95, RMSEA = 0.04) focused on attitudes, not content challenges, making this study's instrument unique. Setiawan et al.'s (2024) teaching evaluation instrument (α = 0.865, AVE > 0.50) and Kurbanoğlu and Takunyacı's (2017) P-LAS (α = 0.94) targeted different constructs, reinforcing the novelty of this study's focus on atomic and nuclear physics. Ahmad et al.'s (2024) STEM Interest Scale (α = 0.680–0.758, AVE = 0.506) and Freda et al.'s (2021) SAES (α = 0.70–0.90) showed robust psychometrics but addressed broader STEM or engagement, not specific physics domains. The marginal AVE for Problem-Solving and Application Challenges suggests potential item refinement, but the high CR and model fit align with Cheung et al.'s (2024) criteria for acceptability. The dual use of Alpha and Omega enhances reliability assessment, surpassing studies like Badeo and Duque (2023), which relied solely on Alpha (α = 0.745). This study's psychometric rigor ensures trustworthy data for Research Questions 2 and 4, filling a gap for a domain-specific, contextually relevant instrument in Ghana.

4.5.4 Discussion of Results for Research Question 4 (Relative Impact of Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics)

Research Question 4 used relative weight analysis (RWA) to assess the impact of four factors (teaching method, learning resources, students' attitude and interest, assessment and evaluation) on overall challenges, yielding a significant model ($F_{(4, 584)} = 3.132$, $p = 0.0145$) explaining 41.8% of variance (Adjusted $R^2 = 0.415$). Learning resources contributed most (49.04%, $p = 0.0187$), followed by students' attitude and interest (43.12%, $p = 0.0308$), while teaching method (0.61%, $p = 0.6670$) and assessment and evaluation (7.23%, $p = 0.3017$) were not significant. SCT's reciprocal determinism (Bandura, 2014) frames these results, highlighting interactions among environmental (resources, teaching, assessment), personal (attitudes, self-efficacy), and behavioural (engagement) factors.

The significant role of learning resources ($\beta = 0.066$, $p = 0.019$) reflects environmental barriers, as inadequate textbooks and lab equipment (Participant 12) hinder visualisation and hands-on learning, critical for abstract topics according to the Ministry of Education (2023). Students' attitude and interest ($\beta = -0.09018$, $p = 0.0308$) indicate that positive attitudes reduce challenges, aligning with SCT's emphasis on self-efficacy (Bandura, 1982). Negative emotions like anxiety (Participant 14) and boredom (Participant 8) reflect low self-efficacy, driving avoidance behaviours. The non-significant impact of Teaching Method and Assessment and Evaluation is surprising, given their qualitative prominence.

These findings align with Coffie et al. (2020) and Wangchuk et al. (2023), who identified resource constraints as major barriers in Ghana and Bhutan respectively. However, the dominance of learning resources (49.04%) contrasts with Taslidere (2020), where cognitive factors explained 60.6% of physics achievement variance, and affective factors like motivation contributed only 2.3%. Appiah-Twumasi (2024) found self-efficacy (β = 0.192) and personality traits (β = 0.232) as stronger predictors of performance in Ghana, but this study's focus on challenges highlights attitude's role in mitigating difficulties. Mansour et al.'s (2024) finding of school features' negative impact (β = -0.33) supports the resource barrier, but their emphasis on teacher effects (β = -0.14) contrasts with this study's non-significant teaching method result, possibly due to the specific focus on atomic and nuclear physics, where resources are critical.

Ajadi and Amoo (2024) reported self-efficacy as the strongest predictor of physics achievement (β = 0.754, R^2 = 0.565), aligning with this study's emphasis on attitude, but their focus on achievement rather than challenges limits direct comparison. Atchia and Chinapah's (2023) SEM showed school leadership (β = 0.43) and student factors (β = 0.30) as key predictors, but resource constraints were less emphasised, unlike this study's context. Tong et al.'s (2025) focus on algebraic skills (β = 0.797) as a predictor of physics problem-solving aligns indirectly with the mathematics ematical demands challenge but does not address resources or attitudes. This study's RWA approach provides precise quantification, extending the literature by isolating challenge-specific impacts in a domain-specific context.

SCT explains the interplay: inadequate resources lower self-efficacy, reducing engagement, as seen in students' frustration with abstract content (Participant 7). The non-significant teaching and assessment findings may reflect curriculum constraints in Ghana, where resource scarcity overshadows pedagogy (Coffie et al., 2020). This study's focus on atomic and nuclear physics highlights unique resource needs (e.g., simulations), offering a targeted contribution to the literature.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.0 Overview

This chapter provides summary of key results, draws conclusions aligned with the four research questions, outlines practical and theoretical implications, discusses limitations, and suggests directions for future research.

5.1 Summary of Key Findings

The study investigated the challenges SHS students encounter in atomic and nuclear physics, the contributing factors, the psychometric properties of the measurement instruments, and the relative impact of these factors. For Research Question 1, qualitative and quantitative data revealed significant challenges in conceptual understanding, problem-solving and application, and mathematics ematical demands, with a composite mean score of 4.26 (SD = 0.409) indicating “very high challenges” per Pimentel’s (2019) scale. Students struggled with abstract concepts like wave-particle duality and nuclear decay, procedural errors in problem-solving, and mathematics ematical operations involving exponents and graphs, reflecting high cognitive load as per CLT.

Research Question 2 identified five contributing factors through thematic analysis: content difficulty, teaching method, learning resources, students’ attitude and interest, and assessment and evaluation. These factors, interpreted through SCT, highlighted the

interplay of personal (low self-efficacy, negative attitudes), environmental (poor resources, ineffective teaching), and behavioral (avoidance) elements.

Research Question 3 confirmed the psychometric robustness of the "Students' Challenges Questionnaire" and "Factors Contributing to Students' Challenges Questionnaire," with a seven-factor structure explaining 66.979% of variance, excellent fit indices (e.g., CFI = 0.964, RMSEA = 0.052), and strong reliability (Cronbach's Alpha = 0.740 – 0.923, McDonald's Omega = 0.741 – 0.924).

Research Question 4, using relative weight analysis, showed that learning resources (49.04%, p = 0.0187) and students' attitude and interest (43.12%, p = 0.0308) significantly influenced challenges, while teaching method and assessment and evaluation had minimal impact, aligning with SCT's reciprocal determinism. These findings underscore the cognitive, social, and environmental barriers to learning atomic and nuclear physics in a Ghanaian context, supported by reliable and valid measures.

5.2 Conclusions

Based on the findings of the study, it can be concluded that SHS physics students studying in the Atwima Nwabiagya Municipality face substantial challenges in atomic and nuclear physics, driven by the high intrinsic cognitive load of abstract concepts, extraneous load from unclear instructional materials, and limited germane load for schema development, as explained by CLT. Secondly, it can be concluded that content difficulty, ineffective teaching methods, inadequate learning resources, negative student

attitudes, and problematic assessment practices collectively contribute to SHS physics students' challenges in the Atwima Nwabiagya Municipality.

Moreover, it can be concluded that the instruments used to measure challenges and contributing factors are psychometrically robust, with a seven-factor structure, high reliability, and strong validity, aligning with CTT principles. This ensures that the findings are credible and generalisable within the study's context, providing a reliable tool for assessing domain-specific challenges in atomic and nuclear physics. Lastly, it can be concluded that learning resources and students' attitude and interest are the most significant contributors to challenges, explaining nearly 92% of the variance in difficulties. However, the non-significant impact of teaching method and assessment, despite their qualitative prominence, suggests that resource constraints and attitudinal barriers dominate in the teaching and learning of atomic and nuclear physics in the Atwima Nwabiagya Municipality.

5.3 Recommendations or Implications of Findings

The findings of this study have substantial theoretical and practical implications. Theoretically, the study extends CLT by quantifying the cognitive load specific to atomic and nuclear physics, demonstrating how high intrinsic and extraneous loads impede learning in a resource-scarce setting. It enriches SCT by detailing the interplay of environmental and personal factors in a specific physics domain, emphasising the role of resources and attitudes in shaping learning outcomes. The psychometric validation

through CTT provides a model for developing contextually relevant instruments, contributing to educational measurement literature.

Practically, in the Atwima Nwabiagya Municipality, teachers should adopt instructional strategies to reduce cognitive load, such as using simulations, interactive visualisations, and worked examples to clarify abstract concepts like wave-particle duality and nuclear reactions. Simplified textbooks with clear diagrams and scaffolded problem-solving exercises can address extraneous load and support schema development. Teacher training programs should emphasise inquiry-based pedagogies, such as hands-on experiments and real-world applications (e.g., relating nuclear physics to energy production), to enhance engagement and reduce reliance on theoretical instruction.

In addition, schools in Atwima Nwabiagya Municipal should prioritise investment in learning resources, including physics laboratories and digital tools, to facilitate visualisation and practical learning, addressing the significant impact of resource scarcity. Interventions to improve students' attitudes, such as fostering self-efficacy through peer collaboration and positive reinforcement, can mitigate disinterest and anxiety. Assessment practices should be reformed to include clear, well-structured questions and timely, constructive feedback to support self-regulation and learning from mistakes.

Policy-wise, the Ghanaian Ministry of Education should allocate funds for modern physics laboratories and digital learning platforms, particularly in Atwima Nwabiagya Municipality. Furthermore, curriculum revisions should integrate practical applications

and reduce the emphasis on rote memorisation, aligning with global trends in science education. Also, professional development for teachers should focus on active learning strategies and assessment design to address the identified barriers. These interventions can enhance students' learning experiences and outcomes in atomic and nuclear physics, preparing them for advanced STEM studies.

5.4 Limitations of Findings

The conclusions drawn from the study is restricted by some limitations regardless of the insights obtained. Firstly, the study's focus on a single municipality, Atwima Nwabiagya, limits its generalisability to other Ghanaian or international contexts, as regional differences in resources, teacher training, or curriculum implementation may influence findings. Secondly, the exclusive focus on SHS physics students restricts insights into how these challenges manifest at other educational levels, such as tertiary institutions, where physics is also studied, potentially missing variations in cognitive and contextual factors across different academic stages. Also, the marginal AVE (0.435) for the "Problem-Solving and Application Challenges" factor suggests that some items may not fully capture the construct, indicating a need for minor refinement. Lastly, the cross-sectional design limits understanding of how challenges evolve over time or with sustained interventions.

5.5 Suggestions for Further Research

Future research should investigate challenges in atomic and nuclear physics across multiple Ghanaian regions or other developing countries to enhance generalisability and

identify contextual variations. Also, comparative studies examining these challenges at different educational levels, such as tertiary or lower secondary settings, could reveal how cognitive and contextual factors differ across academic stages. In addition, longitudinal studies could explore how challenges and contributing factors evolve over time, particularly with interventions like simulation-based learning or teacher training. Finally, refining the "Problem-Solving and Application Challenges" subscale to improve its AVE and testing the instrument in other physics domains would strengthen its applicability.

REFERENCES

Ab Hamid, M. R., Sami, W., & Sidek, M. H. M. (2017). Discriminant Validity Assessment: Use of Fornell & Lacker Criterion Versus HTMT Criterion. *247th Electrochemical Society Meeting*, 1–6. https://doi.org/10.1088/1742-6596/890/1/012163

Aboagye, G. K., & Avor, I. N. (2025). Influence of Students, Teachers and Learning Facility Factors on Senior High School Students' Physics Learning Interest in Accra Metropolis, Ghana. *East African Journal of Education and Social Sciences*, *6*(1), 78-87.

Achor, E. E., Ellah, B. O., & Omaga, J. O. (2022). Misconceptions and Difficult Concepts as Determinant of Students' Academic Engagement and Retention in Physics. *Jurnal VARIDIKA*, *34*(1), 42–52. https://doi.org/10.23917/varidika.v1i1.17660

Ahmad, Z., Sultana, A., Siby, N., Ammar, M., & Al-Thani, N. J. (2024). A Multi-Dimensional Scale for Measuring Undergraduates Interest in STEM Disciplines. *Journal of Science Education and Technology*, *34*, 611–620. https://doi.org/10.1007/s10956-024-10140-w

Aithal, A., & Aithal, P. S. (2020). Development and Validation of Survey Questionnaire & Experimental Data – A Systematical Review-based Statistical Approach. *International Journal of Management, Technology, and Social Sciences (IJMTS)*, *5*(2), 233–251. https://doi.org/10.2139/ssrn.3724105

Ajadi, T. A., & Amoo, O. K. (2024). Psychological Factors Influencing Students' Achievement in Physics in Ogbomoso, Oyo State, Nigeria. *Faculty of Natural and Applied Sciences Journal of Mathematics ematics and Science Education*, *6*(1).

Anindyarini, R., & Rosnawati, R. (2019). A Construct Validity of Spatial Literacy Instrument. *Journal of Physics: Conference Series*, *1397*, 1–11. https://doi.org/10.1088/1742-6596/1397/1/012092

Appiah-Twumasi, E. (2024). Predicting Physics Students' Academic Performance: The Impact of Attitude, Self-Efficacy, and Personality Traits. *Journal of Research in Education and Pedagogy*, *1*(2), 107–117. https://doi.org/10.70232/jrep.v1i2.13

Appiah-Twumasi, E., Ameyaw, Y., & Kwasi Anderson, I. (2022). Development and Validation of Questionnaire for Physics Learning Self-Efficacy among Ghanaian Senior High Schools. *East African Journal of Management and Business Studies*, *2*(1), 8–18. https://doi.org/10.46606/eajess2022v03i01.0141

Asriadi, A. M., & Sanam, A. I. (2025). Psychometric evaluation of diagnostic test instruments on physics wave material. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *29*(1), 71–84. https://doi.org/10.21831/pep.v29i1.84655

Assem, H. D., Nartey, L., Appiah, E., & Aidoo, J. K. (2023). A Review of Students ' Academic Performance in Physics : Attitude, Instructional Methods , Misconceptions and Teachers Qualification. *European Journal of Education and Pedagogy*, *4*(1), 84–92. https://doi.org/10.24018/ejedu.2023.4.1.551

Atchia, S. M. C., & Chinapah, V. (2023). Factors Influencing the Academic Achievement of Secondary School Students: A Structural Equation Model. *International Journal of Instruction*, *16*(1), 999–1020. https://doi.org/10.29333/iji.2023.16155a

Atlabachew, T. K. (2021). *Undergraduate Physics Students' Understanding and Representations of Introductory Nuclear Physics Concepts* (Doctoral dissertation, University of South Africa (South Africa)).

Badeo, J. M. O., & Duque, D. A. G. (2023). Reliability and Validity of Colorado Learning Attitudes about Science Survey (CLASS). *International Journal of Research in STEM Education*, *5*(1), 95–105. https://doi.org/10.31098/ijrse.v5i1.1191

Bahariniya, S., Ezatiasar, M., & Madadizadeh, F. (2021). A Brief Review of the Types of Validity and Reliability of scales in Medical Research. *International Journal of Phytoremediation*, *10*(2), 100–102. https://doi.org/10.18502/jchr.v102.6582

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American psychologist*, *37*(2), 122.

Bandura, A. (1989). Human agency in social cognitive theory. *American psychologist*, *44*(9), 1175.

Bandura, A. (1991). Social cognitive theory of self-regulation. *Organizational behavior and human decision processes*, *50*(2), 248-287.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual review of psychology*, *52*(1), 1-26.

Bandura, A. (2014). Social-cognitive theory. In *An introduction to theories of personality* (pp. 341-360). Psychology Press.

Besnoy, K. D., Dantzler, J. A., Besnoy, L. R., & Byrne, C. (2016). Using Exploratory and Confirmatory Factor Analysis to Measure Construct Validity of the Traits, Aptitudes, and Behaviors Scale (TABS). *Journal for the Education of the Gifted*.

Biasutti, M., & Frate, S. (2017). A validity and reliability study of the Attitudes toward Sustainable Development scale. *Environmental Education Research*, *23*(2), 214.

Brahmia, S., Boudreaux, A., & Kanim, S. E. (2016). Obstacles to mathematics ematization in introductory physics. *arXiv preprint arXiv:1601.01235*.

Bray, A., & Williams, J. (2018). Why is Physics hard? Unpacking Students' Perceptions of Physics. *International Conference on Physics Education*, *1512*, 1–10. https://doi.org/10.1088/1742-6596/1512/1/012002

Brown, G. T. L. (2023). Principles and assumptions of psychometric measurement. *Revista Digital de Investigacion En Docencia Universitaria*, *17*(2), 1–9. https://doi.org/10.19083/ridu.2023.1834

Cappelleri, J. C., Lundy, J. J., & Hays, R. D. (2014). Overview of Classical Test Theory and Item Response Theory for Quantitative Assessment of Items in Developing Patient- Reported Outcome Measures. *Clinical Therapeutics*, *36*(5), 648–662. https://doi.org/10.1016/j.clinthera.2014.04.006

ÇermiK, H. (2020). From the Perspectives of High School Students: Difficulties in the Process of Learning Physics. *International Journal of Eurasian Education and Culture*, *5*(9), 793–822. https://doi.org/10.35826/ijoecc.144

Cheung, D. (2017). The key factors affecting students' individual interest in school science lessons. *International Journal of Science Education*, *40*(1), 1–23. https://doi.org/10.1080/09500693.2017.1362711

Cheung, G. W., Cooper-Thomas, H. D., Lau, R. S., & Wang, L. C. (2024). Reporting reliability, convergent and discriminant validity with structural equation modeling: A review and best-practice recommendations. *Asia Pacific Journal of Management*, *41*(2), 745–783. https://doi.org/10.1007/s10490-023-09871-y

Chew, S. L., & Cerbin, W. J. (2021). The cognitive challenges of effective teaching. *Journal of Economic Education*, *52*(1), 17–40.

Clarke, E., & Visser, J. (2018). Pragmatic Research Methodology in Education: Possibilities and Pitfalls. *International Journal of Research and Method in Education*, *42*(5), 1–30. https://doi.org/10.1080/1743727X.2018.1524866

Coffie, I. S., Frempong, B. B., & Appiah, E. (2020). Teaching and learning physics in senior high schools in Ghana: the challenges and the way forward. *Advances in Research*, *21*(3), 35-42.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (8th ed). Routledge.

Creswell, J. W. (2009). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. In V. Knight, S. Connelly, L. Habib, S. K. Quesenberry, & M. P. Scott (Eds.), *SAGE Publications. Inc.* (3rd ed.).

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). SAGE Publications, Inc.

Dahal, B. K. (2022). Students' and Teachers' Perceptions on Effective Physics Teaching and Learning. *Curriculum Development Journal*, *30*(44), 30–46. https://doi.org/10.3126/cdj.v30i44.54972

De-Moya-Romero, J. R., Valera-Lloris, R., Chover-Sierra, E., Fernández-Puerta, L., Caballero-Bonafé, A., & Martínez-Sabater, A. (2025). Validation, Content Validity, and Reliability of the Spanish SE-OAM Questionnaire: Assessing Nursing Self-Efficacy in Oral Anticoagulant Therapy Management. *Clinics and Practice*, *15*(6), 111. https://doi.org/10.3390/clinpract15060111

Docktor, J. L., Strand, N. E., Mestre, J. P., & Ross, B. H. (2015). Conceptual problem solving in high school physics. *Physical Review Special Topics - Physics Education Research*, *11*(2), 1–13. https://doi.org/10.1103/PhysRevSTPER.11.020106

Ejike, O. O., Adelakun, A., Theophilus, E., & Thomas, T. G. (2025). A systematic review of machine learning and deep learning approaches for load and energy consumption prediction in contemporary power systems. *Journal of Innovation Materials, Energy, and Sustainable Engineering*, *3*(1), 1-20.

Ewim, E. R. D., Nundlal, Y., Govender, K., Nzuke, N. L., Mbatha, M. V., Gwexa, N., Naidoo, K., Laseinde, O. T., & Abolarin, S. M. (2023). Knowledge , awareness , and perception of senior high school learners towards nuclear energy : A South African case study. *African Journal of Science, Technology, Innovation and Development*, *1*(1), 1–19. https://doi.org/10.1080/20421338.2023.2213965

Freda, M. F., Raffaele, D. L. P., Esposito, G., Ragozin, G., & Testa, I. (2021). A new measure for the assessment of the university engagement: The SInAPSi academic engagement scale (SAES). *Current Psychology*, *42*, 9674–9690. https://doi.org/10.1007/s12144-021-02189-2

Frey, F. (2017). Test theory, classical test theory. *International Encyclopedia of Communication Research Methods*, 1-6.

Gale, J., Alemdar, M., Cappelli, C., & Morris, D. (2021). A Mixed Methods Study of Self-Efficacy, the Sources of Self-Efficacy, and Teaching Experience. *Frontiers in Education*, *6*, 1–16. https://doi.org/10.3389/feduc.2021.750599

Garver, M. S., & Williams, Z. (2019). Utilizing relative weight analysis in customer satisfaction research. *International Journal of Market Research*, 1–18. https://doi.org/10.1177/1470785319859794

Ghana Statistical Service. (2021). *District Analytical Report: Mampong Municipal*. 1.

Ginty, A. T. (2020). Construct validity. In *Encyclopedia of behavioral medicine* (pp. 538-538). Cham: Springer International Publishing.

Goretzko, D., Pham, T. T. H., & Bühner, M. (2021). Exploratory factor analysis: Current use, methodological developments and recommendations for good practice. *Current Psychology*, *40*(7), 3510–3521. https://doi.org/10.1007/s12144-019-00300-2

Goretzko, D., Siemund, K., & Sterner, P. (2024). Evaluating Model Fit of Measurement Models in Confirmatory Factor Analysis. *Educational and Psychological Measurement*, *84*(1), 123–144. https://doi.org/10.1177/00131644231163813

Gousopoulos, D. (2023). Investigating students' scientific reasoning through heuristic and analytical thought processes. *arXiv preprint arXiv:2311.07158*.

Hafnidar, H., Harniati, I., Hailemariam, M., & Handrianto, C. (2021). Students' self-regulation: An analysis of exploratory factors of self-regulation scale. *Spektrum: Jurnal Pendidikan Luar Sekolah (PLS)*, *9*(2), 220-225.

Hair, J. F. J., Hult, T. M. G., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021). *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook* (3rd ed.). Springer Nature Switzerland. https://doi.org/10.1080/10705511.2022.2108813

Harinie, L. T., Sudiro, A., Rahayu, M., & Fatchan, A. (2017). Study of the Bandura's Social Cognitive Learning Theory for the Entrepreneurship Learning Process. *Social Sciences*, *6*(1), 1–6. https://doi.org/10.11648/j.ss.20170601.11

Harvey, N. D. (2021). *A Simple Guide to Inter-rater , Intra-rater and Test-retest Reliability for Animal Behaviour Studies*. University of Nottingham.

Hayes, A. F., & Coutts, J. J. (2020). Use Omega Rather than Cronbach's Alpha for Estimating Reliability. But…. *Communication Methods and Measures*, *14*(1), 1–24. https://doi.org/10.1080/19312458.2020.1718629

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-Based Nursing*, *18*(3), 66–67. https://doi.org/10.1136/eb-2015-102129

Hoyle, R. H., & Gottfredson, N. C. (2015). Sample Size Considerations in Prevention Research Applications of Multilevel Modeling and Structural Equation Modeling. *Prevention Science*, *16*(7), 987–996. https://doi.org/10.1177/00221465155946 31

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Hughes, D. (2018). Psychometric Validity: Establishing the Accuracy and Appropriateness of psychometric measures. In *The Wiley Handbook of Psychometric Testing: A Multidisciplinary Approach to Survey, Scale and Test Development*. John Wiley & Sons Ltd.

Hussain, S., Yasmin, R., Chouhdary, A. N., Irfan, M., Munir, F., Ahmad, S., Afzal, M., Liaqa, M., Ibrahim, U., & Khan, W. Z. (2025). From Atomic Nuclei to Nanostructures: Harnessing the Convergence of Nuclear Physics, Particle Dynamics, and Nanotechnology to Transform Energy, Revolutionize Medicine, and Advance Environmental Sustainability. *Global Scientific and Academic Research Journal of Multidisciplinary Studies*, *4*(1), 87–117. https://doi.org/10.5281/zenodo.14789142

Ishtiaq, A., & Ishtiaq, S. (2021). Reliability and validity: Importance in Medical Research. *Journal of the Pakistan Medical Association*, *71*(10), 2401–2406. https://doi.org/10.47391/JPMA.06-861

Japashov, N., Abdikadyr, B., Balta, N., Maxutov, S., Postiglione, A., & Tzafilkou, K. (2024). Analysing the structure of Kazakhstan university undergraduate students' knowledge about the force concept: findings from a three-tier FCI survey. *Physics Education*, *59*(2), 1–17. https://doi.org/10.1088/1361-6552/ad1656

Kaltakci-Gurel, D. (2021). Turkish Adaptation and Psychometric Evaluation of the Colorado Learning Attitudes About Science Survey (CLASS) in Physics. *The European Educational Researcher*, *4*(3), 355–372. https://doi.org/10.31757/euer.435

Klimova, B., Zamborova, K., Cierniak-Emerych, A., & Dziuba, S. (2022). University Students and Their Ability to Perform Self-Regulated Online Learning Under the COVID-19 Pandemic. *Frontiers in Psychology*, *13*(March), 1–10. https://doi.org/10.3389/fpsyg.2022.781715

Kurbanoğlu, N. İ., & Takunyacı, M. (2017). Development and Evaluation of an Instrument Measuring Anxiety Toward Physics Laboratory Classes Among University Students. *Journal of Baltic Science Education*, *16*(4), 592–599.

Leavy, P. (2017). *Research Design: Quantitative, Qualitative, Mixed Methods, Arts-Based, and Community-Based Participatory Research Approaches*. The Guilford Press.

Lim, W. M. (2024). A typology of validity: content, face, convergent, discriminant, nomological and predictive validity. *Journal of Trade Science*, *12*(3), 155–179. https://doi.org/10.1108/jts-03-2024-0016

Lin, W. L., & Yao, G. (2024). Concurrent validity. In *Encyclopedia of quality of life and well-being research* (pp. 1303-1304). Cham: Springer International Publishing.

Mansour, N., Çevik, M., Yağci, A., Alotaibi, S. B. M., & El-Deghaidy, H. (2024). Modeling the Factors Influencing Secondary Students' Performance in Stem Subjects. *Journal of Baltic Science Education*, *23*(3), 518–535. https://doi.org/10.33225/JBS E/24.23.518

Ministry of Education. (2023). *Physics Curriculum for Secondary Education (SHS 1 - 3)*. National Council for Curriculum and Assessment.

Mohajan, H. K. (2017). Two criteria for good measurements in research: Validity and reliability. *Annals of Spiru Haret University. Economic Series*, *17*(4), 59-82.

Morales López, A. I., & Tuzón Marco, P. (2020). Misconceptions, knowledge, and attitudes towards the phenomenon of radioactivity. *Science & Education*, *31*(2), 405-426.

Musah, M. (2022). *Factors affecting teaching and learning of physics in Ghanaian senior high schools a case study in Greater-Accra Region* (Doctoral dissertation, University of Education Winneba).

Mutambo, D., Baliga, G. T., & Nkhata, L. (2018). Investigating Students' Physico-mathematics ematical Difficulties in Classical Mechanics and Designing an Instructional Model. *American Journal of Educational Research*, *6*(8), 1127–1136. https://doi.org/10.12691/education-6-8-10

Ntumi, S., Agbenyo, S., & Bulala, T. (2023). Estimating the Psychometric Properties (Item Difficulty, Discrimination and Reliability Indices) of Test Items using Kuder-Richardson Approach (KR-20). *Shanlax International Journal of Education*, *11*(3), 18–28. https://doi.org/10.34293/education.v11i3.6081

O'Connor, C., & Joffe, H. (2020). Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines. *International Journal of Qualitative Methods*, *19*(1), 1–13. https://doi.org/10.1177/1609406919899220

Obilor, E. I., & Miwari, G. U. (2022). Content Validity in Educational Assessment. *International Journal of Innovative Education Research*, *10*(2), 57–69. www.seahipaj.org

Onwuegbuzie, A. J., & Collins, K. M. T. (2007). A Typology of Mixed Methods Sampling Designs in Social Science Research. *The Qualitative Report*, *12*(4), 281–316. http://www.nova.edu/ssss/QR/QR12-2/onwuegbuzie2.pdf

Paas, F., & van Merriënboer, J. J. G. (2020). Cognitive-Load Theory: Methods to Manage Working Memory Load in the Learning of Complex Tasks. *Current Directions in Psychological Science*, *29*(4), 394–398. https://doi.org/10.1177/0963721420922183

Pallant, J. (2011). *SPSS Survival Manual: A Step by step guide to data analysis using SPSS* (4th editio). Allen & Unwin.

Park, M. (2020). Students' problem-solving strategies in qualitative physics questions in a simulation-based formative assessment. *Disciplinary and Interdisciplinary Science Education Research*, *2*(1), 1–13. https://doi.org/10.1186/s43031-019-0019-4

Pimentel, J. L. (2019). Some Biases in Likert Scaling Usage and its Correction. *International Journal of Sciences: Basic and Applied Research*, *45*(1), 183–191. http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Praharaj, S. K., & Ameen, S. (2024). Sample Size Estimation in Research: Necessity or Compromise? *Kerala Journal of Psychiatry*, *37*(1), 66–71. https://doi.org/10.30834/KJP.37.1.2024.463

Purwanto, A., & Sudargini, Y. (2021). Partial Least Squares Structural Squation Modeling (PLS-SEM) Analysis for Social and Management Research : A Literature Review. *Journal of Industrial Engineering & Management Research*, *2*(4), 114–123. https://doi.org/10.7777/jiemar.v2i4

Rahman, M. (2023). Sample Size Determination for Survey Research and Non-Probability Sampling Techniques: A Review and Set of Recommendations. *Journal of Entrepreneurship, Business and Economics*, *11*(1), 42–62.

Raykov, T., & Marcoulides, G. A. (2016). On the Relationship Between Classical Test Theory and Item Response Theory: From One to the Other and Back. *Educational and Psychological Measurement, 76*(2), 325–338. https://doi.org /10.1177/00131644 15576958

Reddy, V. B. M., & Panacharoensawad, B. (2017). Students Problem-Solving Difficulties and Implications in Physics: An Empirical Study on Influencing Factors. *Journal of Education and Practice, 8*(14), 59–62. www.iiste.org

Rismawati, K. (2023). Analysis of the Validity and Reliability of Indonesian Vocabulary Mastery Instrument Items Using AIKEN'S Model Calculations. *Schola, 1*(1), 17–22. https://doi.org/10.26877/schola.v1i1.121

Roemer, E., Schuberth, F., & Henseler, J. (2021). HTMT2–an improved criterion for assessing discriminant validity in structural equation modeling. *Industrial Management and Data Systems, 121*(12), 2637–2650. https://doi.org/10.1108/IMDS-02-2021-0082

Saka, A. Z., Ebenezer, J., & Saka, T. (2024). Turkish Pre-Service Teachers' Perceptions of Factors Influencing Physics Problem-Solving Abilities. *Science Insights Education Frontiers, 20*(1), 3173–3200. https://doi.org/10.15354/sief.24.or505

Sartika, D., & Humairah, N. A. (2018). Analyzing Students' Problem Solving Difficulties on Modern Physics. *2nd International Conference on Statistics, Mathematics ematics, Teaching, and Research*, *1028*(1). https://doi.org/10.1088/1742-6596/1028/1/012205

Sepp, S., Howard, S. J., Tindall-Ford, S., Agostinho, S., & Paas, F. (2019). Cognitive Load Theory and Human Movement: Towards an Integrated Model of Working Memory. *Educational Psychology Review*, *31*(2), 293–317. https://doi.org/10.1007/s10648-019-09461-9

Setiawan, R., Wagiran, W., & Alsamiri, Y. (2024). Construction of an instrument for evaluating the teaching process in higher education: Content and construct validity. *Research and Evaluation in Education*, *10*(1), 50–63. https://doi.org/10.21831/reid.v10i1.63483

Shrestha, N. (2021). Factor Analysis as a Tool for Survey Analysis. *American Journal of Applied Mathematics ematics and Statistics, 9*(1), 4–11. https://doi.org/10.12691/ajams-9-1-2

Sijtsma, K. (2015). Classical test theory. In *Routledge international handbook of advanced quantitative methods in nursing research* (pp. 29-43). Routledge.

Singh, A. S. (2017). Common Procedures for Development: Validity and Reliability of a Questionnaire. *International Journal of Economics, Commerce and Management, 5*(5), 790–801.

Sithole, A., Chiyaka, E. T., McCarthy, P., Mupinga, D. M., Bucklein, B. K., & Kibirige, J. (2017). Student Attraction, Persistence and Retention in STEM Programs: Successes and Continuing Challenges. *Higher Education Studies*, *7*(1), 46. https://doi.org/10.5539/hes.v7n1p46

Souza, A. C. D., Alexandre, N. M. C., & Guirardello, E. D. B. (2017). Psychometric properties in instruments evaluation of reliability and validity. *Epidemiologia e servicos de saude*, *26*, 649-659.

Sujati, H., Sajidan, Akhyar, M., & Gunarhadi. (2020). Testing the construct validity and reliability of curiosity scale using confirmatory factor analysis. *Journal of Educational and Social Research*, *10*(4), 229–237. https://doi.org/10.36941/JESR-2020-0080

Sukarelawan, M. I., Sulisworo, D., Jumadi, Kuswanto, H., & Rofiqah, S. A. (2021). Heat and temperature metacognition awareness inventory: A confirmatory factor analysis. *International Journal of Evaluation and Research in Education*, *10*(2), 389–395. https://doi.org/10.11591/ijere.v10i2.20917

Summers, R., & Abd-El-Khalick, F. (2018). Development and validation of an instrument to assess student attitudes toward science across grades 5 through 10. *Journal of Research in Science Teaching*, *55*(2), 172–205. https://doi.org/10.1002/tea.21416

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and instruction*, *4*(4), 295-312.

Sweller, J. (2011). Cognitive load theory. In *Psychology of learning and motivation* (Vol. 55, pp. 37-76). Academic Press.

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Taslidere, E. (2020). Factors affecting 12th-grade students' physics achievement. *Psychology in the Schools*, *57*(9), 1–19. https://doi.org/10.1002/pits.22415

Tavakol, M., & Wetzel, A. (2020). Factor Analysis: a means for theory and instrument development in support of construct validity. *International Journal of Medical Education*, *11*, 245–247. https://doi.org/10.5116/ijme.5f96.0f4a

Tindan, T. N., & Arthur, J. M. (2024). Understanding senior high school students' difficulties in learning physics. *International Journal of Multidisciplinary Research and Growth Evaluation*, *5*(2), 494–498.

Tong, T., Pi, F., Zheng, S., Zhong, Y., Lin, X., & Wei, Y. (2025). Exploring the Effect of Mathematics ematics Skills on Student Performance in Physics Problem-Solving: A Structural Equation Modeling Analysis. *Research in Science Education*, *55*(3), 489–509. https://doi.org/10.1007/s11165-024-10201-5

van Nooijen, C. C. A., de Koning, B. B., Bramer, W. M., Isahakyan, A., Asoodar, M., Kok, E., van Merrienboer, J. J. G., & Paas, F. (2024). A Cognitive Load Theory Approach to Understanding Expert Scaffolding of Visual Problem-Solving Tasks: A Scoping Review. *Educational Psychology Review*, *36*(1), 1–42. https://doi.org/10.1007/s10648-024-09848-3

Viladrich, C., Angulo-Brunet, A., & Doval, E. (2017). A journey around alpha and omega to estimate internal consistency reliability. *Anales de Psicologia*, *33*(3), 755–782. https://doi.org/10.6018/analesps.33.3.268401

Wangchuk, D., Wangdi, D., Tshomo, S., & Zangmo, J. (2023). Exploring Students' Perceived Difficulties of Learning Physics. *Educational Innovation and Practice*, *6*, 1–11. https://doi.org/10.17102/eip.6.2023.03

Watkins, M. W. (2017). The reliability of multidimensional neuropsychological measures: from alpha to omega. *Clinical Neuropsychologist*, *31*(6–7), 1113–1126. https://doi.org/10.1080/13854046.2017.1317364

Watkins, M. W. (2018). Exploratory Factor Analysis: A Guide to Best Practice. *Journal of Black Psychology*, *44*(3), 219–246. https://doi.org/10.1177/0095798418771807

Watson, J. C. (2017). Establishing evidence for internal structure using exploratory factor analysis. *Measurement and Evaluation in Counseling and Development*, *50*(4), 232–238. https://doi.org/10.1080/07481756.2017.1336931

WAEC Chief Examiners' Report. (2020). *Chief Examiners' Reports on Physics*. West African Examinations Council.

WAEC Chief Examiners' Report. (2021). *Chief Examiners' Reports on Physics*. West African Examinations Council

WAEC Chief Examiners' Report. (2022). *Chief Examiners' Reports on Physics*. West African Examinations Council

WAEC Chief Examiners' Report. (2023). *Chief Examiners' Reports on Physics*. West African Examinations Council

WAEC Chief Examiners' Report. (2024). *Chief Examiners' Reports on Physics*. West African Examinations Council

Zailinawati, A. H., Schattner, P., Mazza, D., Keluarga, K., & Lumpur, K. (2006). Doing a Pilot: Why is it Essential? *Malaysian Family Physician*, *1*(3), 170–173.

Ziyokhonovna, G. N. (2020). Didactic bases of teaching "Physics of atomic and nuclear structure" in continuous physics education. *International Journal on Integrated Education*, *3*(9), 56–58. https://doi.org/10.31149/ijie.v3i9.588

Zulkiffli, N. S., Fadzil, A. F. M., Noor, N. H. M., Johari, N. A., Othman, E. S., & Nazri, N. A. A. (2024). Exploring the Students' Difficulties in Physics Subject among Secondary School Students During Learning in Class. *International Journal of Academic Research in Business and Social Sciences*, *14*(4), 407–417. https://doi.org/10.6007/ijarbss/v14-i4/21199.

APPENDICES

APPENDIX A

Interview Guide for Exploring Student Experiences in Atomic and Nuclear Physics (For exploring the challenges and their contributing factors)

Introduction: Thank you for agreeing to participate in this interview. My name is James Clarke Hayford, and I am conducting a study to understand students' experiences and challenges in learning atomic and nuclear physics. There are no right or wrong answers, and I am interested in hearing your honest thoughts and perspectives. Everything you share will be kept confidential and used only for this research. This interview will take approximately 30 minutes. Do you have any questions before we begin?

Interview Questions:

1. To start, could you tell me a bit about your overall experience so far with learning atomic and nuclear physics? What comes to mind when you think about these topics?
2. When you're studying atomic and nuclear physics, what are some of the specific ideas, theories, or calculations that you find most challenging or confusing? Can you give me an example of something that was particularly difficult to grasp?
3. How do you generally feel about learning atomic and nuclear physics? Are there times when you feel particularly engaged, frustrated, or anxious about it? Can you describe those feelings?
4. Could you describe how atomic and nuclear physics topics are typically taught in your classes? Are there any specific teaching approaches that you find especially helpful or unhelpful for your understanding?

5. What kinds of learning materials, resources, or tools do you usually use when studying atomic and nuclear physics (e.g., textbooks, diagrams, online videos, lab equipment, practice problems)? How well do they support your learning, or what do you feel might be missing?
6. When it comes to tests or assignments in atomic and nuclear physics, what are your experiences like? Are there certain types of questions or assessment methods that you find particularly challenging or unfair?
7. How much opportunity do you feel you have to ask questions or discuss concepts that confuse you during atomic and nuclear physics lessons?
8. Do you see the connection between what you learn in atomic and nuclear physics and real-world applications or your future career goals? Does this perception affect your motivation to learn?
9. If you could suggest one change to make learning atomic and nuclear physics easier or more enjoyable for students, what would it be?
10. Is there anything else about your experience with atomic and nuclear physics that you think is important for me to know, which we haven't discussed yet?

Conclusion: Thank you very much for sharing your insights and time. Your perspective is very valuable to this study. Do you have any final questions for me?

APPENDIX B

Initial Questionnaire for Students' Challenges in Atomic and Nuclear Physics

Instructions: Please indicate the extent to which you agree or disagree with the following statements regarding the challenges you encounter in the teaching and learning of Atomic and Nuclear Physics.

Challenge Dimension	**Item**	**Item No.**	**Level of Agreement**				
Conceptual Understanding Challenges (CC)	Atomic structures are complex, and I struggle to understand their components.	CUC1	**SA**	**A**	**N**	**D**	**SD**
	The behaviour of subatomic particles is difficult for me to grasp.	CUC2	**SA**	**A**	**N**	**D**	**SD**
	I find the relationship between energy levels and electron transitions confusing.	CUC3	**SA**	**A**	**N**	**D**	**SD**
	The concepts of radioactivity and decay processes are hard to understand.	CUC4	**SA**	**A**	**N**	**D**	**SD**
	I find it hard to connect atomic theory with practical applications.	CUC5	**SA**	**A**	**N**	**D**	**SD**
	I have difficulty understanding the laws governing nuclear energy production.	CUC6	**SA**	**A**	**N**	**D**	**SD**

	I struggle to differentiate between different nuclear reactions (e.g., fission, fusion).	CUC7	**SA**	**A**	**N**	**D**	**SD**
	The dual nature of particles and waves (wave-particle duality) is confusing to me.	CUC8	**SA**	**A**	**N**	**D**	**SD**
	The mathematics ematical equations used in atomic and nuclear physics are too complicated for me.	CUC9	**SA**	**A**	**N**	**D**	**SD**
Problem-Solving and Application Challenges (PSC)	I find it hard to set up and solve quantitative problems in atomic and nuclear physics.	PSC1	**SA**	**A**	**N**	**D**	**SD**
	I struggle to connect atomic and nuclear theory with practical applications.	PSC 2	**SA**	**A**	**N**	**D**	**SD**
	Applying formulas and equations correctly to solve complex atomic and nuclear physics problems is challenging.	PSC 3	**SA**	**A**	**N**	**D**	**SD**
	I have difficulty analysing and interpreting experimental data in atomic and nuclear physics.	PSC 4	**SA**	**A**	**N**	**D**	**SD**
	It is hard for me to explain real-world	PSC 5	**SA**	**A**	**N**	**D**	**SD**

	phenomena using atomic and nuclear physics principles.						
	I find it difficult to translate word problems into mathematics ematical expressions in this subject.	PSC 6	**SA**	**A**	**N**	**D**	**SD**
	I often make errors when performing calculations for atomic and nuclear physics problems.	PSC7	**SA**	**A**	**N**	**D**	**SD**
	I struggle to determine the correct formulas or principles to use for a given problem.	PSC8	**SA**	**A**	**N**	**D**	**SD**
	I find it hard to critically evaluate the solutions to atomic and nuclear physics problems.	PSC9	**SA**	**A**	**N**	**D**	**SD**
Mathematics ematical Demands Challenges (MDC)	I have trouble finding enough detailed examples of solved problems in atomic and nuclear physics.	MDC1	**SA**	**A**	**N**	**D**	**SD**
	I lack the necessary mathematics ematical background (e.g., algebra, logarithms, basic calculus) for atomic and nuclear physics.	MDC 2	**SA**	**A**	**N**	**D**	**SD**

	The mathematics ematical equations used in atomic and nuclear physics are too complicated for me.	MDC 3	**SA**	**A**	**N**	**D**	**SD**
	Performing calculations involving exponents, scientific notation, and significant figures accurately is a challenge.	MDC 4	**SA**	**A**	**N**	**D**	**SD**
	I find it difficult to interpret and use graphs related to atomic and nuclear processes (e.g., decay curves, energy level diagrams).	MDC 5	**SA**	**A**	**N**	**D**	**SD**
	The abstract nature of the mathematics ematics often used in this subject makes it harder to learn.	MDC 6	**SA**	**A**	**N**	**D**	**SD**
	Understanding derivations of mathematics ematical formulas in atomic and nuclear physics is challenging.	MDC 7	**SA**	**A**	**N**	**D**	**SD**

APPENDIX C

Final Questionnaire for Students' Challenges in Atomic and Nuclear Physics

Challenge Dimension	**Item**	**Item No.**	**Level of Agreement**				
Conceptual Understanding Challenges (CUC)	I find the relationship between energy levels and electron transitions confusing.	CUC3	**SA**	**A**	**N**	**D**	**SD**
	The concepts of radioactivity and decay processes are hard to understand.	CUC4	**SA**	**A**	**N**	**D**	**SD**
	I find it hard to connect atomic theory with practical applications.	CUC5	**SA**	**A**	**N**	**D**	**SD**
	I have difficulty understanding the laws governing nuclear energy production.	CUC6	**SA**	**A**	**N**	**D**	**SD**
Problem-Solving and Application Challenges (PSC)	Applying formulas and equations correctly to solve complex atomic and nuclear physics problems is challenging.	PSC 3	**SA**	**A**	**N**	**D**	**SD**
	I have difficulty analysing and interpreting experimental data in atomic and nuclear physics.	PSC 4	**SA**	**A**	**N**	**D**	**SD**

	It is hard for me to explain real-world phenomena using atomic and nuclear physics principles.	PSC 5	**SA**	**A**	**N**	**D**	**SD**
	I find it difficult to translate word problems into mathematics ematical expressions in this subject.	PSC 6	**SA**	**A**	**N**	**D**	**SD**
Mathematics ematical Demands Challenges (MDC)	The mathematics ematical equations used in atomic and nuclear physics are too complicated for me.	MDC 3	**SA**	**A**	**N**	**D**	**SD**
	Performing calculations involving exponents, scientific notation, and significant figures accurately is a challenge.	MDC 4	**SA**	**A**	**N**	**D**	**SD**
	I find it difficult to interpret and use graphs related to atomic and nuclear processes (e.g., decay curves, energy level diagrams).	MDC 5	**SA**	**A**	**N**	**D**	**SD**
	The abstract nature of the mathematics ematics often used in this subject makes it harder to learn.	MDC 6	**SA**	**A**	**N**	**D**	**SD**

APPENDIX D

Initial Questionnaire for Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics

Factor	Item	Item No.	Level of Agreement				
Teaching Method	My physics teacher does not break down complex atomic and nuclear physics concepts sufficiently.	TM1	**SA**	**A**	**N**	**D**	**SD**
	The teaching methods used by my physics teacher do not allow for active student participation during atomic and nuclear physics lessons.	TM2	**SA**	**A**	**N**	**D**	**SD**
	My physics teacher often skips important foundational concepts in atomic and nuclear physics.	TM3	**SA**	**A**	**N**	**D**	**SD**
	I find that the teaching is not tailored to my learning style in atomic and nuclear physics.	TM4	**SA**	**A**	**N**	**D**	**SD**
	I rarely have opportunities to ask questions in class about atomic and nuclear physics.	TM5	**SA**	**A**	**N**	**D**	**SD**
	There are not enough practical demonstrations to support the	TM6	**SA**	**A**	**N**	**D**	**SD**

	theoretical lessons.						
	My physics teacher does not relate atomic and nuclear physics topics to real-world applications, making it difficult for me to engage.	TM7	**SA**	**A**	**N**	**D**	**SD**
Learning Resources	The textbook explanations of atomic and nuclear physics are too advanced and difficult to follow.	LR1	**SA**	**A**	**N**	**D**	**SD**
	The diagrams and visuals used by my physics teacher do not help me understand atomic and nuclear concepts.	LR2	**SA**	**A**	**N**	**D**	**SD**
	I have trouble finding enough detailed examples of solved problems in atomic and nuclear physics.	LR3	**SA**	**A**	**N**	**D**	**SD**
	My school lacks sufficient lab equipment to conduct experiments related to atomic and nuclear physics.	LR4	**SA**	**A**	**N**	**D**	**SD**
	I would benefit from more interactive resources, like simulations or apps, to understand	LR5	**SA**	**A**	**N**	**D**	**SD**

	atomic and nuclear physics.						
	The learning materials provided by my teacher do not help clarify difficult atomic and nuclear physics topics.	LR6	**SA**	**A**	**N**	**D**	**SD**
	I have difficulty finding atomic and nuclear physics study guides or revision materials.	LR7	**SA**	**A**	**N**	**D**	**SD**
	There are not enough resources to help me study atomic and nuclear physics outside of class.	LR8	**SA**	**A**	**N**	**D**	**SD**
Students' Attitude and Interest	I find atomic and nuclear physics boring.	SAI1	**SA**	**A**	**N**	**D**	**SD**
	I feel anxious when faced with atomic and nuclear physics assignments or exams.	SAI2	**SA**	**A**	**N**	**D**	**SD**
	I am easily frustrated when trying to learn atomic and nuclear physics.	SAI3	**SA**	**A**	**N**	**D**	**SD**
	I have a strong dislike for studying atomic and nuclear physics.	SAI4	**SA**	**A**	**N**	**D**	**SD**
	I lack interest in atomic and nuclear physics because it seems too	SAI5	**SA**	**A**	**N**	**D**	**SD**

	challenging.						
	I do not see the relevance of atomic and nuclear physics to my future career or life goals.	SAI6	**SA**	**A**	**N**	**D**	**SD**
	I often feel stressed about learning new concepts in atomic and nuclear physics.	SAI7	**SA**	**A**	**N**	**D**	**SD**
	I would rather avoid atomic and nuclear physics topics because I find them too difficult.	SAI8	**SA**	**A**	**N**	**D**	**SD**
	I feel overwhelmed by the amount of content I need to learn in atomic and nuclear physics.	SAI9	**SA**	**A**	**N**	**D**	**SD**
Assessment and Evaluation	The test questions on atomic and nuclear physics often cover only difficult areas.	AE1	**SA**	**A**	**N**	**D**	**SD**
	I struggle with time management during atomic and nuclear physics exams.	AE2	**SA**	**A**	**N**	**D**	**SD**
	The feedback provided on my atomic and nuclear physics assessments is not detailed enough to help me improve.	AE3	**SA**	**A**	**N**	**D**	**SD**

	Atomic and nuclear physics tests focus on concepts not thoroughly covered in class.	AE4	**SA**	**A**	**N**	**D**	**SD**
	The structure of atomic and nuclear physics tests does not allow me to demonstrate my understanding.	AE5	**SA**	**A**	**N**	**D**	**SD**
	My performance in atomic and nuclear physics are lower than in other topics because of the difficulty of the assessments.	AE6	**SA**	**A**	**N**	**D**	**SD**

APPENDIX E

Final Questionnaire for Factors Accounting for Students' Challenges in the Teaching and Learning of Atomic and Nuclear Physics

Factor	Item	Item No.	Level of Agreement				
Teaching Method	The teaching methods used by my physics teacher do not allow for active student participation during atomic and nuclear physics lessons.	TM2	**SA**	**A**	**N**	**D**	**SD**
	My physics teacher does not break down complex atomic and nuclear physics concepts sufficiently.	TM3	**SA**	**A**	**N**	**D**	**SD**
	I find that the teaching is not tailored to my learning style in atomic and nuclear physics.	TM4	**SA**	**A**	**N**	**D**	**SD**
	I rarely have opportunities to ask questions in class about atomic and nuclear physics.	TM5	**SA**	**A**	**N**	**D**	**SD**
	There are not enough practical demonstrations to support the theoretical lessons.	TM6	**SA**	**A**	**N**	**D**	**SD**
Learning Resources	I have trouble finding enough detailed examples of solved problems in atomic	LR3	**SA**	**A**	**N**	**D**	**SD**

	and nuclear physics.						
	My school lacks sufficient lab equipment to conduct experiments related to atomic and nuclear physics.	LR4	**SA**	**A**	**N**	**D**	**SD**
	I would benefit from more interactive resources, like simulations or apps, to understand atomic and nuclear physics.	LR5	**SA**	**A**	**N**	**D**	**SD**
	The learning materials provided by my teacher do not help clarify difficult atomic and nuclear physics topics.	LR6	**SA**	**A**	**N**	**D**	**SD**
Students' Attitude and Interest	I am easily frustrated when trying to learn atomic and nuclear physics.	SAI3	**SA**	**A**	**N**	**D**	**SD**
	I have a strong dislike for studying atomic and nuclear physics.	SAI4	**SA**	**A**	**N**	**D**	**SD**
	I lack interest in atomic and nuclear physics because it seems too challenging.	SAI5	**SA**	**A**	**N**	**D**	**SD**
	I do not see the relevance of atomic and nuclear physics to my future career or life goals.	SAI6	**SA**	**A**	**N**	**D**	**SD**
Assessment and	The feedback provided on my atomic and nuclear physics assessments is not	AE3	**SA**	**A**	**N**	**D**	**SD**

Evaluation	detailed enough to help me improve.						
	Atomic and nuclear physics tests focus on concepts not thoroughly covered in class.	AE4	**SA**	**A**	**N**	**D**	**SD**
	The structure of atomic and nuclear physics tests does not allow me to demonstrate my understanding.	AE5	**SA**	**A**	**N**	**D**	**SD**
	My performance in atomic and nuclear physics are lower than in other topics because of the difficulty of the assessments.	AE6	**SA**	**A**	**N**	**D**	**SD**