UNIVERSITY OF EDUCATION, WINNEBA

# EFFECTS OF FLIPPED CLASSROOM LEARNING ON STUDENTS' PERFORMANCE, RETENTION AND PERCEPTION TOWARDS ELECTRON CONFIGURATION

FRANCIS KWADJO ADDO

MASTER OF PHILOSOPHY

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**(220022076)**

**A dissertation in the Department of Chemistry Education, Faculty of Science Education submitted to the School of Graduate Studies in partial fulfilment of the requirements for the award of the degree of Master of Philosophy (Chemistry Education) in the University of Education, Winneba**

**JANUARY, 2024**

# DECLARATION

## Student's Declaration

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

SIGNATURE……………………………….

DATE: ……………………………………...

## Supervisor's Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidance for supervision of the thesis as laid down by the University of Education, Winneba.

Name of Supervisor: Dr. Boniface Yaayin

Signature:. ....……………………………

Date: ……………………………………..

## ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to Dr. Boniface Yaayin, my dedicated supervisor, for his invaluable guidance, unwavering support, and insightful feedback throughout the entire research process. His expertise and mentorship have been instrumental in shaping this dissertation. I extend my sincere appreciation to the Head of the Science Department of Mankessim Senior High and Technical School for the encouragement and resources provided. I would also like to acknowledge the ICT Coordinator for facilitating the integration of technology in the research. Your assistance has greatly enhanced the quality and effectiveness of the flipped classroom approach.

Thank you so much to the students of Mankessim Senior High and Technical School for your enthusiastic engagement and commitment to our project. Your willingness to engage in the flipped classroom approach has been crucial to the success of this research.

Once again, thank you to all who played a role in this journey. Your support has been immeasurable.

## DEDICATION

To my beloved wife Mrs. Patricia Addo, your unwavering support, patience, and encouragement have been my pillars of strength. To my cherished children Kiyan and Paris, your laughter and joy have been a constant source of motivation.

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# ABSTRACT

This study investigated the effects of flipped classroom learning on students' academic performance, retention and perception towards electron configuration in a senior high school chemistry setting. The study, conducted at Mankessim Senior High Technical School in Ghana, addressed the prevalent issue of students' inadequate conceptual understanding of electron configuration. Utilising a single-group pre- and post-test action research design, the intervention involved a four-week implementation of the flipped classroom learning approach. The findings revealed a significant improvement in students' academic performance, with a notable difference in mean scores between pre-test and post-test due to the flipped classroom learning approach. The magnitude of the effect on the students' performance was large. The study also found that the flipped classroom learning approach was effective in retaining electron configuration concepts among the students. The findings further showed that students reported high comfort, increased independence, active engagement, and a more effective and enjoyable learning experience through the flipped classroom learning approach. The study concludes that the flipped classroom learning approach is a valuable pedagogical tool for enhancing students' academic performance, retention and perception towards electron configuration in chemistry education. The study recommends the integration of flipped classroom methodology in teaching electron configuration and other chemistry topics in the selected school.

# CHAPTER ONE

# INTRODUCTION

## 1.0 Overview

This chapter presents the background to the study and the statement of the problem. It also contains the purpose of the study, research objectives, corresponding research questions and research hypotheses. It ends with the significance of the study, limitation of the study, delimitation and organization of the study.

## 1.1 Background to the Study

Many students in Ghanaian Senior High School perceive chemistry education as dealing with the most abstract content among the sciences. The abstract nature of chemistry, combined with the requirement to comprehend concepts that are not directly observable, adds to the subject's challenge (Stowe & Cooper, 2019). An essential aspect of starting chemistry education in Ghana's Senior High School is establishing the concept of electron configuration, which involves discussing atomic orbitals and is fundamental to the study of other chemistry topics. The importance of electron configuration to the study of other chemistry concepts cannot be underestimated, yet it is one of the most challenging topics for students in senior high school. Students' comprehension of electron configuration lays a good foundation for the study of periodicity, hybridization, and other topics in chemistry.

The idea of electron configuration, which explains how electrons are organised within an atom, originates from the Bohr atomic model. This model emerged after the discovery of electrons. However, the primary interest of this study is in the electron configuration that stems from a subsequent atomic model, known as quantum mechanics' atomic model. This model was introduced in 1927 through Schrodinger's equation. According to this model, an electron configuration is defined by four quantum numbers: the principal quantum number (n), azimuthal quantum number (l), magnetic quantum number (m), and magnetic spin quantum number (s) (Chang, 2010). To accurately write electron configurations, students must understand the significance of these four quantum numbers. Additionally, they must understand and apply three fundamental rules: Aufbau's principle, Hund's rule, and Pauli's Exclusion Principle, which govern the arrangement of electrons in atomic orbitals (Anslyn & Dougherty, 2006).

However, it is important to note that achieving a correct understanding of electron configuration requires more than just knowledge of these principles. In order to understand the abstract nature of electron configuration, students must also possess adequate knowledge of atomic symbols, atomic numbers, the concept of atoms and ions, as well as the ability to determine the number of protons and electrons in an atom. Since students have never directly observed an atom, these concepts may appear foreign and unfamiliar to them. Consequently, establishing connections between these relevant concepts becomes crucial for constructing a robust understanding of electron configuration.

To address the challenges associated with students comprehending electron configuration, it is essential to implement effective instructional strategies. Several studies have explored various approaches to enhance students' understanding in this area. One study conducted by Bio, Saurdana and Kima (2014) investigated chemistry teachers' knowledge and application of electron configuration. The findings revealed that teachers often struggle with accurately explaining the concept and its related principles. This highlights the importance of teacher professional development programs that focus on deepening their understanding of electron configuration and effective instructional strategies. Additionally, Choda and Chenprakton (2015) conducted a comparative study examining the difficulties students face in understanding electron configuration based on their learning approaches. The results indicated that students who adopted a surface approach, merely memorising information without a deep conceptual understanding, encountered more difficulties in comprehending electron configuration compared to those who utilised a deep approach. These findings emphasise the significance of promoting meaningful learning experiences that encourage students to actively engage with the underlying principles and concepts of electron configuration.

Tsaparlis and Papaphotis (2002) identified a lack of solid understanding of atomic orbitals among students, suggesting that their understanding is primarily derived from textbooks or teachers. To enhance students' understanding of electron configuration, it is imperative to relate this concept to other relevant concepts. In light of these research findings, implementing instructional strategies that facilitate students' comprehension of electron configuration becomes crucial. Educators can incorporate interactive activities such as modelling exercises, computer simulations, and hands-on laboratory experiments to provide students with concrete experiences related to electron configuration. These experiences help students bridge the gap between the abstract nature of the concept and their understanding of the submicroscopic world. Furthermore, integrating technology into the learning process can enhance students' engagement and understanding of electron configuration. Online resources, virtual laboratories, and interactive visualisation tools can aid in visualising complex concepts, allowing students to explore and manipulate electron configurations in a dynamic and interactive manner.

To attain a comprehensive understanding of chemical knowledge, it is vital to explicitly teach the interplay between the submicroscopic, microscopic, and symbolic levels (Aydin-Gunbatar & Akin, 2022). Given that atoms are inherently invisible to the naked eye, students must comprehend the concepts at both the microscopic and symbolic levels to fully comprehend ideas such as electron configuration. Difficulties in comprehending this topic may arise if students lack a solid foundation of understanding on these two levels. In order to bridge the gap and facilitate students' comprehension, it becomes essential for educators to emphasise the relationship between the submicroscopic world of atoms, the observable microscopic world, and the symbolic representations used in chemistry. By explicitly teaching the connections between these levels, students can develop a more holistic understanding of chemical phenomena.

By guiding students to visualise and relate the sub microscopic structure of atoms with the observable behaviour at the microscopic level, they can begin to understand the significance of electron configuration and its implications in chemical reactions. Simultaneously, nurturing their ability to interpret and manipulate symbolic representations, such as electron configurations in formula or equations, allows for a more robust understanding of the subject matter. This multifaceted approach enables students to bridge the gap between the invisible realm of atoms and the observable world, fostering a deeper understanding of the intricacies of chemistry.

Our understanding of learning is based on the growth of mental structures that enable the student to apply the "pattern of thinking" learned in the classroom to other learning situations or in their daily lives, taking into account social-historical psychology (Vygotsky, 1978). The most significant issue with teaching chemistry, according to Primon and Arroio (2016), is how concepts are introduced. The ideas should make it possible for students to understand chemistry without having to memorize definitions or use meaningless formulae and words. The language or ideas that students employ should, ideally, gradually influence their way of thinking.

According to a study conducted by Ezema et al. (2022), the occurrence of conceptual change in chemistry education relies on the design of lessons that encourage students to express their own ideas and challenge them against accepted scientific viewpoints. To foster meaningful discussions, it is crucial for teachers to establish a supportive learning environment that allows students to freely articulate their thoughts without the fear of being ridiculed. Consensus in the field suggests that promoting students' collaboration, integrating technology, and employing effective teacher facilitation all contribute to enhanced academic achievement in secondary level chemistry classrooms (Pondee & Srisawasdi, 2021).

Consequently, numerous research studies have recommended a comprehensive transformation of our public education system (Osei, 2006) and have proposed that educators explore alternative approaches to traditional classroom settings (Akyeampong, 2017). The advent of the Internet has revolutionized education, providing learners with extensive access to technological resources as alternatives to traditional teaching approaches. According to Symonds (2013) and Yusuf (2006), technology has made information readily available, allowing individuals to access and share it anytime, anywhere. In the modern world, Information Communication Technology (ICT) has become relevant in various aspects of human life, including education (Yusuf et al., 2013). Information Communication Technology resources, such as email, mail lists, newsgroups, and chat groups, facilitate easy information dissemination among scholars and support research activities, including design, analysis, data production, storage, and dissemination (Yusuf et al., 2013). According to Yusuf (2006), ICT encompasses diverse communication devices and applications, such as computers, social networks, and satellite systems, enabling e-learning, virtual teaching and learning, and e-training. Similarly, Asamoah, Asiedu, and Baudi (2022) asserts that the use of ICT in education caters to students' needs, learning styles, aspirations, and provides a wide range of learning experiences. Employing multimedia in educational settings has proven effective in enhancing performance and retention rates (Oshinaike & Adekunmisi, 2012).

Researchers have indicated that active learning pedagogy coupled with instructional technology innovations has led to the adoption of the flipped classroom model (Bergmann & Sams, 2012; Zappatore, 2023). It is however important to recognize that while students today are highly adaptable to new technologies, educators should not overlook the significance of direct instruction, which plays a crucial role in the learning process (Zappatore, 2023).

The Flipped Classroom Learning (FCL) method of instruction effectively combines the strengths of both traditional teaching methods and modern technology to facilitate the dissemination of concrete information and foster critical evaluation among learners, leading to improved performance and retention. The relevance and the choice of the flipped classroom learning approach in this study cannot be downplayed. The FCL model stands out from other teaching approaches, such as video conferencing, computer-based teaching (CBT), and mobile learning, which lack the interactive nature of a direct classroom session. For instance, pre-recorded videos on various subjects for primary and secondary school students, stored on CD or DVD, may only benefit a selected group of students, as there is no opportunity for feedback or assessment of their understanding and comprehension of complex concepts (Bergmann & Sams, 2012). Furthermore, students are deprived of the invaluable one-on-one interaction with their teachers, making it difficult to address individual needs and modify teaching approaches based on students' contributions.

The flipped classroom-learning model offers a dynamic alternative by utilising technology to engage students actively in the learning process. By assigning pre-recorded teachings and educational materials as homework, class time can be dedicated to collaborative activities, discussions, and problem-solving exercises. This interactive approach allows students to delve deeper into the subject matter, apply their knowledge, and receive immediate feedback from their peers and instructors (Bergmann & Sams, 2012). Consequently, students develop stronger cognitive, emotional, behavioural, and agentic engagement, resulting in more positive perceptions towards the flipped classroom across various areas of learning (Herreid & Schiller, 2013).

Research conducted by O'Flaherty and Philips (2015) revealed that the flipped classroom learning approach not only enhances student satisfaction but also improves communication skills, as students actively participate in class discussions and collaborate with their peers. During in-class sessions, students also engage in-group activities, discussions, and peer teaching, which enhances their understanding of electron configuration through interaction and collaboration (Barfi et al., 2023; Salame et al., 2011). This approach not only encourages knowledge sharing, but also develops communication and teamwork skills, which are crucial for students' holistic developments. This heightened engagement leads to a richer learning experience, promoting better retention of the acquired knowledge. The flipped classroom learning model emphasises the importance of student-centred learning, where learners take ownership of their education and actively contribute to the learning process (O'Flaherty & Philips, 2015).

Teachers gain the confidence to customise the curriculum for a group of students while in the classroom because enough classroom time allows the teacher to work with students more individually per this pedagogy (Aidoo et al., 2022). Teachers can also deliver more meaningful lessons because they do not have to repeat instructions as frequently. Although research on the FCL has been increasing immensely in recent years, there is still a dearth of study performed in senior high school chemistry education in Ghana, specifically teaching of electron configuration. Additionally, there is limited research on how flipped classroom learning approach impacts students' self-efficacy, learning experience and learning achievement. Researchers have noted that, when students are not provided with sufficient assistance when modelling detailed knowledge and proficiency, their learning achievement and self-efficacy may reduce substantially (Fitriza & Gazali, 2018). As a result, this study employed the flipped classroom learning approach in teaching electron configuration to an intact class in Mankessim Senior High Technical School (MSHTS) in the Central Region of Ghana.

## 1.2 Statement of the Problem

The problem in this current study is the inadequate conceptual understanding of electron configuration among students of Mankessim Senior High Technical School (MSHTS) in Central Region of Ghana. Numerous variables contribute to students' struggles in conceptualising and comprehending a subject matter. The method that instructors use to present the lesson and how ready the students are to receive the information cognitively are two of the main elements that facilitate students' understanding of scientific concepts. The problem of students' inadequate conceptual understanding of electron configuration starts with students' misunderstanding of atomic orbitals due to poor orbital visualisation on their part (Osei-Owusu, 2007). Students do not significantly comprehend the origin of the nomenclature used to describe the atomic orbitals of 's, p, d, and f' during class time. This results in nuclear shells being used as a replacement for energy levels, which is erroneous. Students also struggle to differentiate between the group (or family) and period of the periodic table when provided simply the atomic number. The inability of students to demonstrate the precise electron configuration of an atom from its ground state to its ion form and utilise electron configuration to forecast the magnetic properties of atoms adds to the understanding issue. Students' of Mankessim Senior High Technical School (MSHTS) in Central Region of Ghana are not exempted from the issues that other students face regarding conceptual understanding of electron configuration (EC). The researcher, who is also a teacher at MSHTS had identified this problem among the students through classroom teaching and learning sessions.

For a student, the electron configuration (EC) holds a fundamental domain in the development of chemical concepts. The students' capacity to establish a good command of the chemistry subject provides them with a solid platform for manipulating another scientific chemical knowledge. The electron configuration is a prerequisite knowledge for understanding most courses in the chemistry syllabus, so students may find it difficult to create straightforward concept maps connecting to other subject areas if they lack understanding of this fundamental concept. In the long-term, it may lead students to substandard academic achievement in the chemistry subject during their final West African Senior School Certificate Examination (WASSCE).

The impact on higher education is extremely severe. According to Hanson et al. (2012), the majority of undergraduates lack the necessary background knowledge in electron configuration. Dorris and Rau (2022) reaffirmed this in a report on how undergraduate chemistry students confused the numerous atomic orbital representations and lacked a comprehensive knowledge on atomic and molecular orbitals. As a result, whenever conceptual questions are asked relating to electron configuration, they perform poorly.

The weight of the chemistry curriculum and its abstract context coupled with the challenge of Senior High Schools, facing limited resources, including textbooks and laboratory equipment is problematic. The flipped classroom learning approach can overcome these constraints by leveraging online resources and videos, which can be accessed by students even if physical resources are scarce (Ahmed et al., 2020). By using digital platforms and readily available resources, the flipped classroom learning enables students to access quality instructional materials regardless of their geographical location. Flipped learning is a student-centred method in which students receive pre-lessons electronically and spend class time participating in active learning. Instead of passive listening during lectures, students can engage with the instructional content at their own pace before coming to class. This approach promotes self-directed learning, critical thinking, and problem-solving skills, which are essential for understanding complex topics like electron configuration and other chemistry topics (Abeysekera & Dawson, 2015; Nyagblormase, Yaayin & Hanson, 2023). Active engagement during in-class activities and discussions further solidifies the understanding of concepts. Even though there might be equally good students-centred instructional methods for teaching electron configuration, the FCL appears to create a relaxing and convenient environment for students through the watching of videos. The student enjoys the fun of learning without the teacher factor constantly giving instructions. The current study therefore sought to increase students' understanding and academic performance in electron configuration by adopting the flipped classroom instructional method.

## 1.3 Purpose of the Study

The purpose of the study was to investigate the effects of flipped classroom learning on students' performance, retention and perception towards electron configuration at Mankessim Senior High Technical School (MSHTS) in the Central Region of Ghana.

## 1.4 Objectives of the Study

The objectives of this study were to:

1. Access students' conceptual understanding of electron configuration before the flipped classroom learning approach.
2. Determine the effect of flipped classroom learning on students' performance in electron configuration.
3. Determine the effect of flipped classroom learning on students' retention of electron configuration concepts.
4. Access students' perceptions of the flipped classroom learning towards electron configuration.

## 1.5 Research Questions

The following research questions will guide the study;

1. What is the conceptual understanding of students in electron configuration before the flipped classroom learning approach?
2. What is the effect of flipped classroom learning on students' performance in electron configuration?

3. What is the effect of flipped classroom learning on students' retention of electron configuration concepts?
4. What are the students' perceptions of the flipped classroom learning approach to electron configuration?

## 1.6 Research Hypotheses

The following null hypotheses were tested at a 0.05 level of significance. Research question two was formulated to null hypothesis one, and research question three was formulated to null hypothesis two.

$H_{01}$: Flipped classroom learning has no significant effect on students' performance in electron configuration.

$H_{02}$: Flipped classroom learning has no significant effect on students' retention of electron configuration concepts.

## 1.6 Significance of the Study

It clearly states the contribution the study is expected to make from the result, conclusion and finally recommendations. The findings of this research would have numerous beneficiaries, including senior high school teachers, students, curriculum planners, educational policy makers, school administrators, professional and examination bodies and fellow researchers.

The teachers, chemistry teachers in particular, would gain a thorough understanding of the advantages of flipped classroom learning (FCL) in teaching through the findings of this study. Consequently, they would be encouraged to undergo educational training to effectively implement the FCL approach. The findings of the study could assist teachers in improving their teaching and assessment methods for better understanding, skills, and knowledge acquisition among learners. It would also enable teachers to capitalise on the benefits of FCL to enhance knowledge transfer.

Furthermore, the results of this research would greatly benefit students. As teachers begin using FCL as a teaching tool or as an aid to their learning, students would experience increased motivation, enhanced learning speed, and improved performance and retention of concepts learnt. The findings would facilitate easier learning for students, regardless of their location. School administrators and the government would become more aware of the necessity of allocating sufficient funds for the acquisition, installation, and utilisation of relevant FCL technology in schools.

Curriculum planners and policymakers could find this study's findings particularly valuable in terms of incorporating specific technologies required for FCL into the curriculum. The emphasis would be on ensuring the provision and improvisation of necessary technology to support FCL instruction. Again, fellow researchers would find this study significant as it may provide suggestions to address the challenges associated with adopting the flipped classroom approach in Ghanaian senior high schools. The study could reinforce the concept of flipped classrooms or introduce them to higher education in Ghana.

### 1.7 Limitations of the Study

According to Fatimah and Syahrani (2022), limitations are challenges that affect a study. As action research, the findings of this study were limited to only MSHTS because the research participants were not selected by randomization. The participants were engaged using an intact class in the school where the study was conducted. The findings therefore, could not be generalised to other senior high schools within the Central Region and Ghana as a whole. All students were not equally disciplined in performing the out-of-class activities due to inadequate supervision, which could affect the outcome of the study, unlike the in-class activities where the teacher fully facilitated the learning process. Since the study was conducted within official class and school schedules, extracurricular activities affected the intervention, particularly, the out-of-class activities, though the teacher made an effort to create time for the students to make up for the lost study time. Students' possible biassed responses to the questionnaire items could affect the findings of the study.

## 1.8 Delimitations of the Study

Delimitation defines the parameters or the scope of the research study (Simon & Goes, 2013). It defines the boundaries of a study such as methodology, geographical area and the theoretical coverage of the study. This current study was conducted in a public Senior High School within the Mfansteman Metropolitan Assembly. The target group for this research was all students who study chemistry as a subject in all Senior High Schools in the Mfansteman metropolis. However, due to limited time and resources the research was delimited to an intact science class of 45 students, who study chemistry as a subject in MSHTS.

Despite a number of instructional design models, this study was restricted to flipped classroom models of instruction within the framework of action research design and the focus was on electron configuration and not all topics in chemistry. The electron configuration as a concept was restricted to content that is studied in the chemistry syllabus for Senior High School students in Ghana.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Overview

This chapter reviews literature that focuses on the theoretical framework, the conceptual framework, and empirical review based on the research questions.

## 2.1 Theoretical Framework

This study is anchored on Vygotsky's social constructivism theory and Bandura's social learning theory. Figure 1 presents the theoretical framework, which serves as the focus of this study and connects to the research problem under study.

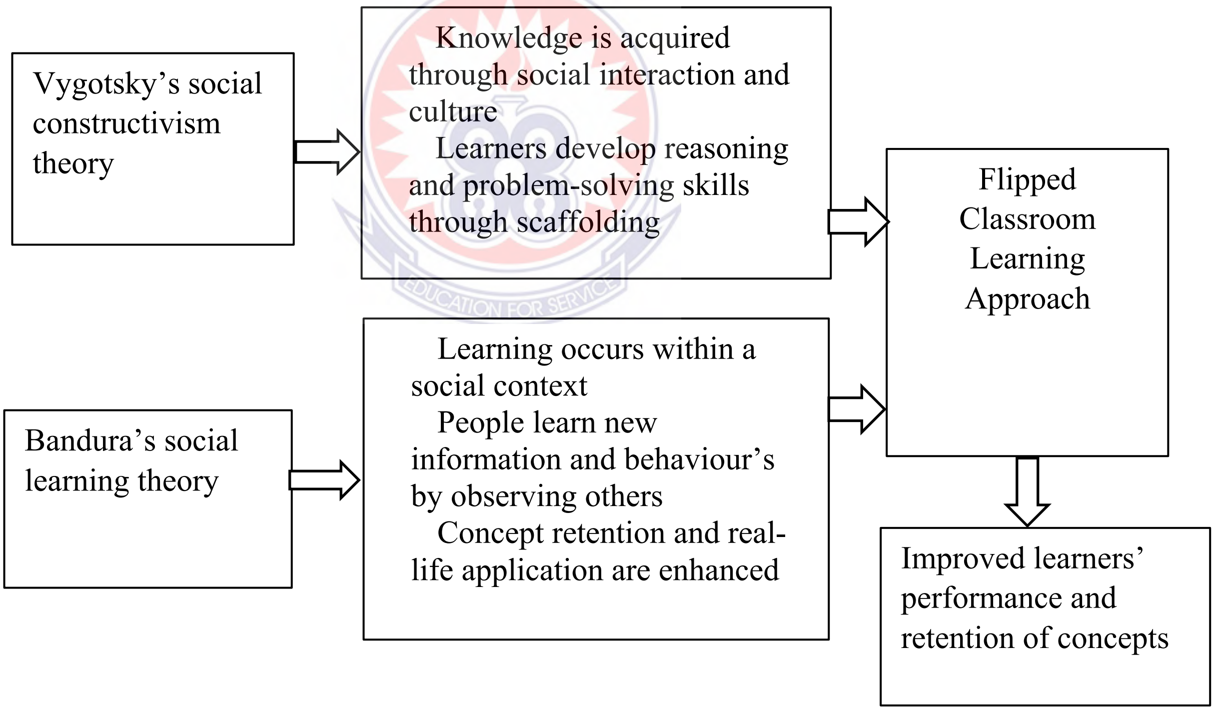


**Figure 1: Theoretical Framework within the Context of Flipped Classroom Learning Approach**

### 2.1.1 Vygotsky social constructivism theory

Vygotsky's social constructivism theory suggests that students acquire knowledge through social interactions and culture and that social exchanges play a critical role in cognitive development (Vygotsky, 1978). Instruction must be designed so that students interact effectively within the classroom and construct their own understanding (Alvarez, 2007; Berrett, 2012). The flipped classroom approach aligns with Vygotsky's theory by providing scaffolding at a meta-cognitive level to support learners' reasoning and problem-solving skills (Suh, 2010). The educator provides appropriate strategies to ensure precision of knowledge for content development, supporting learners' content development by providing suitable activities at the correct level of difficulty and complexity (Lewis, Perry, Friedkin & Roth, 2011).

Vygotsky introduced the Zone of Proximal Development (ZPD) in the 1930s as scaffolding, defined as the distance between what learners comprehend within a task and the next level of learning they can complete with a higher conceptual level of comprehension (Wood, Bruner & Ross, 1976). The ZPD is evident in the flipped classroom, as it requires the facilitator to provide meta-cognitive support and ensure the exactness of student learning, allowing students to become self-regulated and independent (Bergmann & Sams, 2012; Johnson & Renner, 2012). The social interactions and collaborative learning in the flipped classroom help learners develop a deeper understanding of the content area (Vygotsky, 1978). Thus, Vygotsky's social constructivism theory provided a framework for the flipped classroom curriculum, with components such as scaffolding for the learner, the educator as the facilitator, and the ZPD evident in this alternative approach (Lewis et al., 2011). Although the flipped classroom allows learners to understand new knowledge independently, guidance and feedback from a facilitator during class time through social interactions, collaborative and cooperative learning, and peer instruction are crucial for effective learner development (Vygotsky, 1978).

In the flipped classroom, learners access instructional materials, such as videos, outside the class and engage in collaborative and cooperative learning and peer instruction during class time, facilitating the development of the learner effectively (Bergmann & Sams, 2012; Johnson & Renner, 2012). However, the role of the facilitator is crucial in guiding learners' understanding and providing feedback to help learners make deeper meaning of the content area (Alvarez, 2007; Berrett, 2012). Vygotsky's social constructivism theory provides a framework for this alternative curriculum, as the major components of the theory, such as effective scaffolding, the role of the facilitator, and the Zone of Proximal Development, are evident in the flipped classroom (Lewis et al., 2011; Suh, 2010; Vygotsky, 1978; Wood et al., 1976).

Vygotsky's social constructivism theory emphasises that social interactions and culture play a significant role in cognitive development, with social exchanges and interactions playing an essential role in cognitive development (Vygotsky, 1978). The major theme of the social constructivism framework is that learners acquire knowledge through social interactions and their culture to experience meaningful learning (Alvarez, 2007; Berrett, 2012). Vygotsky's theory of the Zone of Proximal Development proposes that scaffolding, which is the support provided by the facilitator to move the learner to the next level, is necessary for learning (Wood et al., 1976). The flipped classroom is rooted in social constructivist theories, emphasising the active role of the students in making decisions through social interaction. Vygotsky's social constructivism theory provides a framework for this alternative curriculum, as the major components of the theory, such as effective scaffolding, the role of the facilitator, and the Zone of Proximal

Development, are evident in the flipped classroom. The facilitator's role is crucial in guiding learners' understanding and providing feedback to help learners make deeper meaning of the content area in the flipped classroom.

### 2.1.2 Bandura's social learning theory

Bandura's Social Learning Theory provided another theoretical framework for the inverted classroom and also explained how learning occurs and is retained (Bandura, 1977). According to Bandura's theory, a student's behaviour and the situation the student is in exert an influence on their next action (Bandura, 1977). This theory emphasises that learning occurs within a social context and involves interactions with other students and adults (Nabavi, 2012).

The premise of the Social Learning Theory is that people learn new information and behaviours by observing others. Bandura believed that learners acquire new behaviours by watching others, forming ideas about how to perform those behaviours, and then imitating them (Bandura, 1977). Observational learning, also known as modelling, encompasses a wide range of learners (Bandura, 1977). Bandura's theory explains the cognitive, environmental, and behavioural influences on human behaviour (Bandura, 1977). For observational learning to be effective, the learner must meet four conditions: attention, retention, reproduction, and motivation (Nabavi, 2012).

In the flipped classroom, the Social Learning Theory is continuously evident. The learner is exposed to media where a presenter models appropriate behaviour. When the learner pays attention to the instruction, retention, reproduction, and motivation are likely to occur (Alvarez, 2012; Fulton, 2012). Bandura's theory provides a theoretical framework for the flipped classroom, as effective modelling of concepts is presented through various media (Alvarez, 2012). The attentive student then retains and reproduces the learned concepts through practice problems and applies them to real-life situations. While the inverted classroom may not address all issues in traditional instruction, it can tackle some of them by promoting student engagement, providing timely feedback, and facilitating student collaborations, thereby enhancing concept retention and real-life application (Alvarez, 2012; Bergmann & Sams, 2012; Berrett, 2012).

The application of Bandura's Social Learning Theory in the flipped classroom is evident through the integration of multimedia resources and interactive activities. In this instructional approach, students have the opportunity to observe and learn from various sources, including online videos and teacher-made videos (Alvarez, 2012). These videos serve as models for appropriate behaviours, demonstrating how concepts are applied in real-life situations.

By actively engaging with the instructional materials, students meet the first condition of observational learning, which is attention. Paying attention to the modelled behaviours sets the foundation for the subsequent conditions to be met (Nabavi, 2012). Once attention is established, students can move on to the retention phase, where they store the observed information in their memory for later recall. Retaining the learned concepts is crucial for students to effectively reproduce the modelled behaviours. In the flipped classroom, students are provided with opportunities to practice and apply the concepts they have observed. Through solving practice problems and engaging in hands-on activities, students reinforce their understanding and develop the necessary skills to reproduce the modelled actions (Nabavi, 2012).

Motivation plays a significant role in observational learning, as learners are more likely to imitate behaviours that are reinforced or rewarded (Nabavi, 2007). In the flipped classroom, students are intrinsically motivated to learn and apply the concepts because they can see the relevance and real-life applications of the knowledge presented (Alvarez, 2012). Additionally, students may receive verbal praise or recognition for their achievements, further enhancing their motivation to continue modelling appropriate actions.

The integration of Bandura's Social Learning Theory in the flipped classroom addresses several challenges associated with traditional instruction. In a traditional classroom setting, students often passively receive information without ample opportunities for active engagement and application (Berrett, 2012). The flipped classroom, on the other hand, promotes student engagement through interactive activities and encourages students to take ownership of their learning. Moreover, timely feedback is an essential component of the flipped classroom, as it enables students to monitor their progress and make necessary adjustments (Bergmann & Sams, 2012). Through on-going feedback and assessment, students can refine their understanding and improve their performance, aligning with Bandura's emphasis on the importance of feedback in the learning process.

Collaboration is another key aspect of the flipped classroom that aligns with Bandura's Social Learning Theory. By working collaboratively with their peers, students have the opportunity to observe and learn from one another (Alvarez, 2012). Group discussions, cooperative projects, and peer feedback enhance the social context of learning, facilitating the transfer of knowledge and skills among students.

In conclusion, the flipped classroom integrates Bandura's Social Learning Theory by providing opportunities for observational learning through the use of multimedia resources and interactive activities. By attending to the conditions of attention, retention, reproduction, and motivation, students can effectively learn and apply the concepts presented. The flipped classroom addresses the limitations of traditional instruction by promoting student engagement, timely feedback, and collaboration, fostering concept retention and real-life application.

### 2.2 Conceptual Framework

The conceptual framework shows the relationship between the variables in the study. The key variables in this study are the independent and dependent variables. Figure 2 presents the conceptual framework of the study.

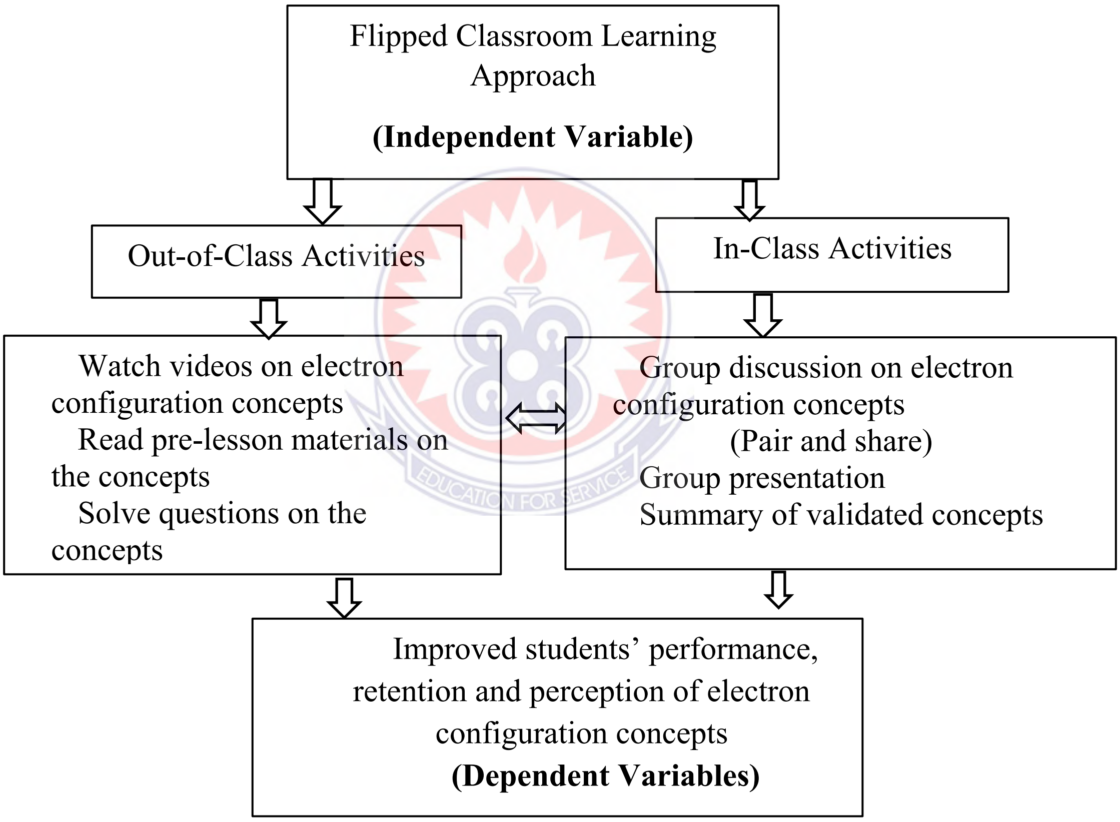


**Figure 2: Conceptual Framework of the Flipped Classroom Learning Approach**

The framework illustrated in Figure 2 elaborates on the relationship between the flipped classroom learning approach, which is considered the independent variable, and the dependent variables, such as students' performance, retention, and perception of electron configuration concepts.

### 2.2.1 Content of the SHS syllabus about electron configuration concept

In the SHS chemistry syllabus, atomic orbitals are treated in the second year of senior high school education under electronic energy levels, which form part of a broader topic, namely atomic structure (MOE, 2010). According to the syllabus, students are to be helped to define an orbital as a concept and, then, construct and describe the shapes and orientations of the *s* and *p* orbitals. It also directs that the origin of the letters *s, p, and d* for the orbital-types as sub-energy levels be explained to students. Also included are the relationships among the main energy levels, sub-energy levels, and the orbitals in an atom. Moreover, the syllabus includes discussions of the number of sub-energy levels in each main energy level up to Krypton (4p) and the number of orbitals in each sub-energy level.

Accordingly, the rules and principles underlying the arrangement of electrons in the shells, sub-shells and orbitals of an atom must be discussed. These are the Aufbau Principle, Hund's Rule of Maximum Multiplicity, and Pauli's Exclusion Principle (MOE, 2010). The syllabus also requires students to be able to write the detailed electronic configurations of the elements in terms of *s, p, d, and f,* and the *x, y,* and *z* directions of the p-orbitals, given the proton (or atomic) number of each element.

#### 2.2.1.1 Bohr's atomic energy levels

According to Bohr (1913), electrons occupy specific energy levels or orbits around the nucleus. The energy of an electron in a specific orbit is quantized and determined by its principal quantum number (n). Electrons can transition between energy levels by absorbing or emitting energy in discrete amounts. These transitions are responsible for the characteristic spectral lines observed in atomic emission and absorption spectra. While Bohr's model successfully explained the stability of atoms and the existence of discrete energy levels, it had limitations. It failed to explain the fine spectral structure observed in more complex atoms and ions. Bohr's model treated electrons as particles moving in fixed circular orbits, but the wave-like nature of electrons required a more sophisticated model. The model did not account for the concept of electron spin, which was later incorporated into quantum mechanics (Reed, 2022).

The development of quantum mechanics revolutionised our understanding of atomic structure and energy levels. Schrödinger's wave equation and the Heisenberg uncertainty principle provided a mathematical framework to describe the behaviour of electrons as waves. Quantum mechanics introduced the concept of atomic orbitals, which are regions of high probability where electrons are likely to be found. Atomic orbitals are described by wavefunctions, which are solutions to the Schrödinger equation. The quantum mechanical model allows for a more detailed understanding of electron behaviour, energy levels, and electron configurations.

#### 2.2.1.2 Origin of s, p, d and f atomic orbital notation

Atomic orbital notation represents the arrangement of electrons within an atom's energy levels and sublevels. The notation is based on the four quantum numbers: principal quantum number (n), azimuthal quantum number ($l$), magnetic quantum number ($ml$), and spin quantum number ($m_s$). Slater (1930) worked on the shielding effect of inner electrons, leading to the development of atomic orbital notation. The *s, p, d,* and *f* orbital notations correspond to different values of the azimuthal quantum number ($l$). The *s* orbital ($l$ = 0) is spherical and can hold a maximum of 2 electrons. The *p* orbitals ($l$ = 1) are dumbbell-shaped and can hold a maximum of 6 electrons (2 electrons in each of the three *p* orbitals). The *d* orbitals ($l$ = 2) have more complex shapes and can hold a maximum of 10 electrons. The *f* orbitals ($l$ = 3) have intricate shapes and can hold a maximum of 14 electrons. The notation provides a convenient way to represent the different shapes and orientations of atomic orbitals, which play a crucial role in determining the electronic structure and chemical properties of atoms and molecules.

**2.2.1.3 Rules for filling atoms with electrons**

The Aufbau principle governs the arrangement of electrons, stipulating their occupation of progressively lower energy levels prior to advancement to higher ones. This principle mandates that electrons populate orbitals in a sequence of increasing energy, adhering to the order of *s, p, d,* and *f* orbitals. The Pauli exclusion principle, on the other hand, establishes that no two electrons within an atom can possess an identical set of four quantum numbers. This tenet implies that each orbital can house a maximum of two electrons with opposing spins. Hund's rule, meanwhile, dictates that electrons first occupy separate orbitals within the same sublevel (such as *p* or *d*) before coming together in pairs within an orbital. Hund's rule serves to minimise electron-electron repulsion, bolstering the stability of the atom.

Collectively, these principles determine the electron configurations of atoms, outlining the precise organisation of electrons within energy levels and sublevels. Hund's work made a significant contribution to the advancement of atomic orbital notation by delving into the role of electron exchange forces in establishing electron configurations. Hund's research focused extensively on electron spin and its impact on electron placement within atoms. His proposition posited that electrons strive to maximise their collective spin, leading to a preference for unpaired electrons occupying distinct orbitals at the same energy level (degeneracy). This concept, termed Hund's rule, elucidates the reasoning behind electrons populating separate orbitals before pairing within a sublevel (such as *p* or *d*). Additionally, Hund's rule aids in explaining certain magnetic and spectroscopic characteristics of atoms and ions (Tielens, 2021).

Hund's work not only enriched our understanding of electron behaviour but also provided a deeper insight into the intricate workings of atomic systems. His investigations revealed the significance of electron spin in influencing the stability and properties of atoms (Barfield & Huebner, 2014). By proposing that electrons seek to maximise their total spin, Hund’s rule laid the foundation for comprehending the arrangement of electrons in ways that align with the atom's inherent tendencies.

Furthermore, Hund's rule has proven instrumental in rationalising various magnetic and spectroscopic attributes exhibited by atoms and ions (Barfield & Huebner, 2014). The rule places emphasis on minimising electron repulsion that leads to a more harmonious distribution of electrons, resulting in more stable configurations. This stability, in turn, contributes to the distinctive characteristics displayed by different elements in their interactions with electromagnetic fields and their emission or absorption of light.

Hund's pioneering contributions have become integral to the realm of quantum mechanics and atomic theory. His rule serves as a guiding principle in deciphering the complexities of electron arrangement, which underlie the diverse behaviours and properties of matter at the atomic scale. As a result, Hund's research has left an indelible mark on the field of atomic physics, illuminating the fundamental principles that govern the intricate dance of electrons within atoms and paving the way for further advancements in our understanding of the microscopic world.

Understanding atomic energy levels and electron configurations is crucial for various areas of science and technology. The knowledge of energy levels and transitions is fundamental to spectroscopy, allowing the identification and analysis of chemical elements and compounds. Electron configurations and orbital notations are essential in predicting chemical reactivity, bonding patterns, and molecular structures (Anslyn & Dougherty, 2006). The periodic table is organized based on electron configurations, providing a systematic representation of elements and their properties. The study of electron filling rules aids in predicting and explaining the periodic trends observed in atomic properties, such as atomic size, ionization energy, and electronegativity.

The study of Bohr's atomic energy levels, the origin of atomic orbital notation, and the rules for filling atoms with electrons have been instrumental in shaping our understanding of atomic structure and behaviour. Bohr's model provided a crucial stepping-stone towards the development of quantum mechanics, which has revolutionised our comprehension of atoms and their energy levels. Theoretical advancements and experimental evidence have provided robust support for the concept of quantized energy levels, the existence of atomic orbitals, and the rules governing electron configurations (Anslyn & Dougherty, 2006). The practical applications of this knowledge span various scientific disciplines, including chemistry, physics, materials science, and spectroscopy. Ongoing research and technological progress continue to expand our knowledge and pave the way for new discoveries and applications related to atomic energy levels and electron behaviour.

### 2.2.2 Self-regulated flipped classroom learning

Within the flipped classroom approach (FCA), learners apply cognitive, motivational, and behavioural strategies to the self-regulated learning (SRL) process (Altas & Enisa, 2020). Unlike passive, traditional learning paradigms, individual pre-class preparation is required for the success of in-class collaborative activities. The shift of responsibility from teacher to student to regulate personal accountability without the structure and organization within the classroom is often fraught with motivation, procrastination, and a reduction in help-seeking behaviour. Successfully overcoming these obstacles and the students' ability to actively influence their own motivation is viewed as an important aspect of their self-regulated learning (Wolters et al., 2011).

Sletten (2015) found significant positive correlations between SRL behaviour and student perceptions of the flipped learning model; however, she recommended that instructors modelling SRL behaviours be included early in the course for maximum benefit. Empirical evidence collected by Butzler (2016) revealed that teacher scaffolding in note-taking ameliorated passive learning in the pre-learning phase and provided students with an opportunity to reflect, summarize, and formatively self-assess their levels of understanding. Utilization of the flipped classroom approach revealed that the SRL performance dimensions of help-seeking, task strategies, and environmental structuring were significantly improved, and cognitive engagement within a social community promoted critical thinking, increased student participation, and higher collective student efficacy (Chen & Hwang, 2018).

### 2.2.3 Students’ engagement in flipped classroom learning

Student motivation to complete out-of-class work must be partially self-determined for active learning to succeed (Abeysekera & Dawson, 2015). With a reliance on personal motivation as a determinant of learning outcomes, creating a supportive and inclusive learning environment that supports students' cognitive needs promotes satisfaction and sustained engagement in the learning process (Deci & Ryan, 2008; Deci et al., 2017). As opposed to passive experience in the transmissive classroom, engaged students have an increased sense of autonomy and competence. As explained by Baron and Corbin

(2012), the involved student is one who has a positive, fulfilling, and work-related state of mind that is characterised by vigour, dedication, and absorption and who views himself or herself as belonging to and an active participant in his or her learning community. According to Niemiec and Ryan (2009), these engaged learning communities, facilitated by teachers who create and maintain collaborative educational climates, increase student satisfaction and self-efficacy in the learning process. As students engage on behavioural, emotional, and cognitive levels, they exercise their autonomy to engage, modify, personalize, and enrich classroom activities to achieve conceptual understanding (Reeve & Tseng, 2011; Garner & Shank 2023) with a positive instructor and peer relatedness.

The level of student-autonomy support that they receive from their instructors in a dialectical framework of self-determination theory that facilitates engagement and contributes to many aspects of students’ achievement (Reeve et al., 2004; Reeve & Tseng, 2011). Implementation of constructivist teaching approaches empowers student engagement in the classroom and encourages students to assume a purposeful role in their learning (Black & Deci, 2000). As active learners, students are more prepared to work collaboratively in groups (O'Flaherty & Phillips, 2015) as well as become more responsible for their individual learning at a self-directed pace (Kim et al., 2016; Lage et al., 2000). When basic psychological needs are fulfilled in student-centred online courses, students' self-determination significantly increases, and desired learning outcomes are achieved (Hsu et al., 2019).

### 2.2.4 Impact of self-regulated learning and students' engagement on science achievement in a flipped classroom

When active learning methodologies are used, self-regulated learning (SRL) has been shown to have a strong correlation with significant improvements in academic achievement in science. The deliberate integration of various self-regulation techniques, including goal setting, temporal organization, and self-evaluation, has emerged as a key strategy for enhancing science education in the flipped classroom paradigm within the educational framework.

Remarkably, recent scholarship, as exemplified by the investigation conducted by Park and Kim (2022), accentuates the indispensable role of instilling adept self-regulation practices in students to optimise their learning processes and, thereby, amplify their scientific accomplishments. In a high school biology class that used a flipped classroom approach, researchers observed a dynamic relationship between student engagement, self-regulation skills, and academic achievement in science. The results of a study by Rasheed et al. (2020) showed that developing students' self-regulation skills had a positive impact on their engagement and ultimately led to better scientific performance. This phenomenon has been studied across various educational levels, as evidenced by research from Hermanns and Schmidt (2019), Sebesta and Speth (2017), Şen and Yilmaz (2016), and Van Horne et al. (2017).

Farrel's (2021) research on non-major post-secondary science students in Germany, for example, demonstrated the effectiveness of using self-regulation tools during complex problem-solving tasks. Similarly, Sebesta and Speth (2016) conducted scholarly research into various self-regulated learning (SRL) strategies. These strategies, such as note and examination review, self-evaluation, seeking information, and setting goals and plans, were found to enhance students' performance gradually. The works of Theresya et al. (2018) and Cilliers and Pylman (2022) also explored SRL in the context of a hybrid-learning program in an Indonesian high school. They found a strong correlation between high levels of SRL and academic success, especially when a virtual chemistry laboratory was integrated. Students' engagement patterns in a flipped science curriculum. The study revealed that proactive and consistent engagement with preparatory materials, including video consumption and virtual discussions, resulted in better exam performance (Sletten, 2015; Winn et al., 2019)

A study by Şen and Yilmaz (2016) found that high school students who were studying electrochemistry had better time management and study environments if they practiced self-regulated learning (SRL). However, the study also showed that SRL does not directly lead to better academic achievement but rather has a mediating effect. Incorporating active learning techniques and focusing on SRL in a flipped classroom setting can improve science education. Many studies have shown that engagement, self-regulation, and academic success are closely linked. These findings help us better understand the complex nature of effective learning strategies in science education.

## 2.3 Empirical Framework

### 2.3.1 Effect of flipped learning on understanding and performance in chemistry

The utilization of the flipped classroom pedagogical approach has garnered attention within the realm of secondary education, particularly in the domain of chemistry instruction. Flipped classrooms have shown a positive impact on senior high school students' understanding and performance in chemistry. In addition to improved understanding and performance, the flipped classroom model also encourages critical thinking and deeper exploration of chemistry topics. Students have more opportunities to ask questions, seek clarification, and engage in hands-on activities during class time (Talbert, 2017; Jensen et al., 2015). This active learning environment has led to a more comprehensive grasp of complex chemical concepts.

Undoubtedly, the efficacy of the flipped classroom model in senior high school chemistry education finds its basis in several critical educational theories and principles. Constructivist learning theory, for instance, posits that learners construct their knowledge through active engagement and meaningful interactions with instructional content. The pre-class video teaching and independent study assignments inherent in the flipped approach align with this theory by prompting students to assume an active role in their learning process (Vygotsky, 1978). The in-person sessions then serve as platforms for the collaborative exchange of ideas, guided by the teacher's facilitation, fostering an environment conducive to the internalization of complex chemical concepts. Moreover, the cognitive load theory emphasizes the importance of managing the cognitive demands placed on learners. Chen and Kalyuga (2020) contend that information processing capacity is limited, necessitating instructional strategies that optimize cognitive resources. The flipped classroom strategy appears to be in consonance with this theory, as students are exposed to initial exposure and encoding of the subject matter independently, reducing cognitive load during in-class activities that demand higher-order thinking (Tofade et al., 2013).

Certainly, a comprehensive understanding of the effects of the flipped classroom model on students' comprehension and performance in chemistry requires an exploration of the cognitive processes and learning outcomes that underlie this pedagogical shift. The cognitive engagement within the flipped classroom structure is closely intertwined with the principles of active learning. Mystakids (2021) postulated that active engagement promotes meaningful learning by facilitating the organization of information into coherent mental structures. The pre-class engagement with video teaching allows students to establish preliminary mental frameworks, enabling them to actively construct connections between new information and their existing knowledge. This preparatory step sets the stage for more in-depth discussions and analytical exploration of chemical concepts during in-person sessions.

In terms of learning outcomes, substantial evidence points towards the favourable impact of the flipped classroom model on performance metrics. A meta-analysis conducted by Van Vliet et al. (2015) indicated that students exposed to flipped instruction consistently outperformed their peers in traditional settings in terms of examination scores and course completion rates. This enhanced performance can be attributed to the personalized nature of the flipped approach, which enables learners to address their specific learning needs and engage in targeted remediation or enrichment. Furthermore, the flipped classroom's approach places emphasis on peer interaction and collaborative problem solving that cultivates a deeper understanding of chemistry concepts. Johnson et al. (2014) asserted that collaborative learning enhances students' ability to articulate their thought processes, defend their ideas, and integrate diverse perspectives. This process of articulation and debate nurtures metacognitive skills, allowing students to reflect on their learning strategies and refine their approaches to problem solving in the realm of chemistry, which enhances performance.

However, it is prudent to acknowledge that the flipped classroom model may not yield uniform outcomes for all students. Factors such as individual learning styles, prior academic preparation, and intrinsic motivation may influence the degree to which students benefit from this approach. As Keating et al. (2017) suggest, instructors should maintain a flexible approach that accommodates diverse learning profiles and provides additional support for students who require it. The benefits of the flipped classroom model are not devoid of potential challenges, however. One concern pertains to the accessibility of technology and resources, which could lead to disparities in the learning experience among students from different socioeconomic backgrounds (Hew & Lo, 2018). Additionally, effective implementation demands the cultivation of a pedagogical shift, necessitating training and support for educators to create well-designed instructional content and interactive classroom activities. While challenges exist, thoughtful integration of this approach can undoubtedly contribute to a more robust and comprehensive chemistry education experience.

Several studies have explored the effects of flipped learning on students' academic performance in various science subjects (Roehl et al., 2013; Yilmaz, 2017). A study by Yang et al. (2019) examined the impact of a flipped learning approach on students' performance in learning the electronic configuration of atoms. The study involved 70 high school students who were randomly assigned to either a flipped learning group or a traditional lecture-based group. The flipped learning group watched instructional videos in electronic configuration before attending class, while the traditional group received lectures during class time. The results of the study showed that the flipped learning group outperformed the traditional group on the post-test assessing the understanding of electronic configuration. The flipped learning group also demonstrated higher levels of engagement, motivation, and interest in the subject matter. The authors suggest that the flipped learning approach provides students with more flexibility and control over their learning and allows for more individualized and personalized instruction.

Another study by Kim et al. (2021) investigated the impact of a flipped learning approach on students' understanding of the electronic configuration of atoms in a college-level chemistry course. The study involved 64 students who were randomly assigned to either a flipped learning group or a traditional lecture-based group. The flipped learning group watched instructional videos and completed online quizzes before attending class, while the traditional group received lectures during class time. The results of the study showed that the flipped learning group performed significantly better on the post-test assessing the understanding of electronic configuration than the traditional group. The authors suggest that the flipped learning approach promotes active learning and engages students in higher-order thinking skills, leading to deeper understanding and better performance on assessments.

More evidence drawn from empirical research has demonstrated the positive implications of the flipped classroom approach for senior high school chemistry education. A study by Lage, Platt and Treglia (2000) observed that the incorporation of pre-class video teaching and at-home assignments resulted in higher levels of student participation during face-to-face sessions. This elevated engagement fostered greater peer interaction, collaborative learning, and heightened critical thinking skills. Moreover, a study by Strayer (2012) revealed that the flipped classroom model promotes the concept of active learning. In contrast to the passive nature of traditional lectures, students are encouraged to apply higher-order cognitive processes such as analysis, synthesis, and evaluation. This active engagement has been attributed to heightened retention rates and increased comprehension of intricate chemical concepts. Furthermore, the flexibility inherent in the flipped classroom approach aligns with the diverse learning needs and preferences of senior high school students. According to Johnson and Renner (2012), learners possess a spectrum of cognitive aptitudes and learning velocities. The ability to revisit instructional materials at their own pace affords struggling students the opportunity to reinforce foundational concepts, while advanced learners can delve into supplementary resources to satiate their intellectual curiosity.

Gilboy, Heinerichs and Pazzaglia (2015) examined the impact of the flipped classroom on student performance and engagement in a general chemistry course. The researchers found that students in the flipped classroom format achieved higher average examination scores compared to traditional lecture-based classes. Moreover, students in the flipped classroom reported increased engagement and a deeper understanding of complex chemical concepts, attributing this to the pre-class preparation that facilitated more active participation during in-class discussions. Abeysekera and Dawson (2015) also analyzed the effects of flipped classrooms on students' learning outcomes across various disciplines. They found that the flipped classroom approach consistently led to improved learning outcomes, including higher grades and better conceptual understanding. Additionally, the flipped classroom fostered a shift from passive to active learning, enhancing critical thinking skills and encouraging students' ownership of the learning process.

Again, Hewson and Beeth (2016) explored the impact of the flipped classroom on high school chemistry students' cognitive load and understanding of chemical kinetics. The study found that the flipped approach reduced cognitive load during in-class activities, allowing students to engage more deeply with challenging concepts. Students' post-test scores improved significantly, suggesting that the flipped classroom contributed to a more effective understanding of complex chemistry topics. Liu et al. (2016), according to their meta-analysis, investigated the effects of the flipped classroom model on students' performance in science courses, including chemistry. The findings indicated that the flipped classroom approach significantly improved students' examination scores, indicating better learning outcomes. Additionally, the flipped classroom positively influenced students' attitudes towards learning and enhanced their satisfaction with the instructional approach.

Similarly, Lin and Huang (2018) investigated the impact of a flipped classroom approach on high school students' conceptual understanding and problem-solving abilities in a chemistry course. The study revealed that students who experienced the flipped classroom had a significantly better understanding of fundamental chemical concepts and demonstrated improved problem-solving skills compared to their counterparts in a traditional classroom setting. The researchers attributed these outcomes to the active engagement and collaborative learning facilitated by the flipped approach. Wanner and Palmer (2015), in their qualitative study, explored students' experiences and perceptions of a flipped classroom in a chemistry course. Students reported that the pre-class video teachings helped them prepare for in-class activities, allowing for more meaningful discussions and exploration of advanced concepts. The interactive nature of the in-person sessions fostered peer interactions, collaborative learning, and a sense of community that contributed to improved understanding and performance in chemistry. Hung (2015) also investigated the effects of the flipped classroom model on students' academic achievement, motivation, and self-regulated learning in a chemistry course. The study found that students in the flipped classroom achieved significantly higher scores on the final examination compared to those in the traditional classroom. Additionally, students in the flipped classroom reported higher motivation levels and a stronger sense of autonomy in managing their learning process, which contributed to their improved performance.

Deslauriers, Wieman and Beichner (2011), physics-focused study, explored the impact of the flipped classroom on student learning outcomes. Although not chemistry-specific, the findings are relevant to STEM education. The study discovered that the flipped classroom approach resulted in increased learning outcomes, as determined by standard concept assessments.

The study highlighted that the flipped approach allowed for more time dedicated to active engagement and problem solving, leading to deeper understanding. These outcomes consistently indicate enhanced conceptual understanding, improved problem-solving skills, increased motivation, and a shift towards active and collaborative learning. These studies collectively reinforce the notion that the flipped classroom approach holds significant promise for advancing chemistry education at the senior high school level.

**2.3.2 Students' retention performance in chemistry**

Chemistry education is a critical component of STEM fields, and understanding factors influencing student retention and performance is essential for educational improvement. One significant factor influencing student retention in chemistry is the teaching method employed. Traditional lecture-based approaches have been scrutinized for their limited effectiveness in promoting deep understanding (Freeman et al., 2014). In contrast, active learning methods, such as flipped classrooms and problem-based learning, have shown promise in enhancing student engagement and retention (Prince, 2004). Research by Stefenile (2020) demonstrated that incorporating active learning strategies in chemistry courses led to higher student retention rates. The study suggested that interactive and participatory activities improved students' comprehension and retention of complex chemical concepts. The integration of technology into chemistry education has also been investigated for its impact on student retention. Interactive simulations, online resources, and virtual laboratories offer students opportunities for hands-on learning experiences outside traditional classroom settings (Herron et al., 2017). For instance, a study by Wang et al. (2018) explored the use of virtual laboratories in teaching chemistry. The findings indicated that students who engaged with virtual experiments demonstrated better retention of concepts compared to those relying solely on traditional lab experiences. Student engagement and motivation play crucial roles in retention and academic performance. Hidi and Renninger (2006) argued that students who are intrinsically motivated are more likely to persist in challenging subjects like chemistry. In the context of chemistry education, Jin and Bridges (2016) found that incorporating real-world and exploring the use of educational technologies in problem-based learning applications and contextual examples increased student interest and motivation, positively correlating with improved retention rates. The quality of instructor-student interaction has been identified as another determinant of student retention in chemistry. Studies have shown that approachable and supportive instructors positively influence students' attitudes and academic performance (Cuseo, 2007; Smith et al., 2011).

### 2.3.3 Students' perceptions on the use of flipped learning in chemistry education

Traditional pedagogical approaches have given way to innovative teaching methods that address the diverse learning preferences of students (Stefenile, 2020). Among these, the flipped classroom approach has emerged as a distinctive paradigm. The flipped classroom approach is being celebrated for its potential to augment students' engagement, critical thinking skills, and autonomous learning abilities. That is why its application holds a particular promise in teaching chemistry, a subject demanding both conceptual comprehension and practical application (Pierce & Fox, 2012; Strayer, 2012). High school students' perceptions of the flipped classroom learning approach in teaching chemistry reflect a diverse range of viewpoints, influenced by learning style, technological familiarity, and adaptability to self-directed learning (Cevikbas & Kaiser 2020; Tsui et al., 2023)

While some students embrace the autonomy and flexibility offered by the flipped model, others struggle with its demands for self-regulation and technological access (Singh et al., 2022). As educators continue to fine-tune their instructional strategies, understanding and accommodating these varying perceptions will be integral to the success of implementing the flipped classroom approach in the context of teaching chemistry to high school students (Vilchez et al., 2021)

Studies have shown that high school students have different views on the flipped classroom approach when it comes to chemistry education (Brame, 2013). While some students appreciate the flexibility of the model and the ability to control their learning pace, others find it challenging due to the need for self-regulation and time management skills (Missildine et al., 2013; Talbert, 2017). Limited access to technology and suitable learning environments at home can also hinder students' participation in the flipped learning approach (Liu, 2022). Those who enjoy self-paced learning can benefit from the flipped classroom's ability to revisit complex concepts and collaborate with peers during in-class activities (Herreid & Schiller, 2013; Mazur, 2009). However, students who struggle with the independent nature of the model may feel isolated and require additional motivation and discipline (O'Flaherty & Phillips, 2015).

The shift from teacher-centred to a more student-centred learning environment can also cause uncertainty and discomfort for some students (Kong, 2014). It is important for educators to keep in mind the diverse needs and preferences of students when implementing the flipped classroom approach. Providing resources and support for students who struggle with time management and self-regulation can help improve their experience. Additionally, offering opportunities for collaboration and group work can enhance the learning experience for all students. Overall, a balanced approach that considers both the benefits and challenges of the flipped classroom can help create a positive and effective learning environment for high school students.

Students tend to find the flipped classroom learning approach more engaging compared to traditional lectures. This is due to the interactive activities and discussions that take place in class, which allow students to actively participate in their learning process (Bishop & Verleger, 2013; Strayer, 2012). Additionally, students appreciate the flexibility of being able to consume instructional content at their own pace outside of class, which accommodates various learning styles and preferences. This also allows them to review complex concepts as needed (Betihavas et al., 2016; Pierce & Fox, 2012). Studies have revealed that the flipped classroom model helps students gain a deeper understanding of chemistry concepts. They value the opportunity to apply theoretical knowledge to practical scenarios during in-class activities (Siddiqui, 2021; Herreid & Schiller, 2013).

Articles often highlight the positive impact of collaborative activities on students' perceptions. The flipped classroom encourages peer interaction, cooperative learning, and constructive discussions (Missildine et al., 2013). Meanwhile, many students thrive in a self-directed learning environment; some articles mention that students can initially find it challenging to take responsibility for their learning and manage their time effectively (Kong, 2014; Lage et al., 2000). Studies have shown concerns related to the digital divide, where students with limited access to technology or a suitable study environment at home might face obstacles to fully participating in the flipped approach (Roach & Lemasters, 2018; Hussain et al., 2020). Students' perceptions of the flipped classroom are often influenced by the instructor's guidance, facilitation, and support. Effective instructor-student interaction is crucial for a positive experience (Herreid & Schiller, 2013; O'Flaherty & Phillips, 2015).

### 2.3.4 Role of educational technology

As new advances in technology continue to expand the horizons of the educational landscape, teachers and learners must adapt and assimilate new learning modalities such as screen casting, vodcasting, and a variety of interactive e-learning platforms into daily practice. Influenced by the dramatic proliferation of social media and the decline of face-to-face interaction, the future of education will be shaped by the convenience of accessibility and the interactions between students and teachers in the digital space (Godwin-Jones, 2020). The increased responsibility for students to independently access and review asynchronous content provided by their instructors requires discipline and accountability. Despite positive reception by students, increased workload by teachers may prevent full integration in high school science classrooms due to constraints of time, access, and digital literacy.

Implementing a flipped classroom learning approach within a Ghanaian high school educational setting is a novel domain due to a lack of technological advancement and strict conventional laws against the use of internet accessing devices within the boarding home system. Nevertheless, a couple of researchers have been successful with its implementation in high schools in Ghana and Nigeria. Boateng et al. (2022) engaged 21 students in a quasi-experimental pre-test design in a flipped classroom learning approach. Findings of the study indicated that, regarding the acquisition of skill sets and the maintenance of academic achievement, the students with flipped classroom learning approaches obtained higher levels of achievement compared with the students in the control group.

**2.3.4.1 Students' use and accessibility of educational technology in flipped learning**

The ability to use asynchronous online materials appeals to the autonomy and agency of digital natives and allows for individual review of challenging topics; however, consistent student access to digital content outside the classroom is a concern (Lee, 2016; Zengin, 2017; Means et al., 2013; Marougkas et al., 2023). Within this new pedagogical framework, successful implementation requires electronic access to course materials for all students. Utilizing the flipped classroom approach is not possible without availability for all stakeholders, and some studies revealed that students and teachers experience technical difficulties in accessing and maintaining digital platforms (Giannakos et al., 2014; O'Flaherty & Phillips, 2015; Zengin, 2017). Monitoring student engagement and tracking the frequency of digital content use were lacking in the reviewed research (Kim et al., 2014; Leo & Puzio, 2016). This lack of knowledge by teachers regarding student-viewing patterns has been one of the greatest detractors of the flipped classroom approach (Urfa, 2018). In this regard, Kim et al. (2021) expressed the need to create a system of student accountability. Similarly, Leo and Puzio (2016) noted that future studies would also be improved by identifying a way to keep track of student video watching and to analyze whether video consumption was correlated with achievement. Mischel (2019) reported that EdPuzzle, a video-sharing program, was valuable for formative assessment of student learning through teacher-embedded questions and voiceovers that clarify and reinforce the retention of viewed video content. In addition, the digital tool Playposit could serve as an alternative digital platform for student tracking (Romero-García et al., 2018).

Understanding, viewing patterns, and determining how video length impacts student retention is integral to further modification in the flipped classroom approach learning cycle (Long et al., 2016; Slemmons et al., 2018). In general, videos were recommended to be less than 20 minutes for content retention and increased student participation (Houston & Lin, 2012; Wagner & Urhahne, 2021).

In an investigation of high school mathematics students, Lo and Hew (2017) suggest that core content should be covered in less than 15 minutes. Guo, Kim and Rubin (2014) reported that asynchronous video content of six minutes or less is correlated with high student satisfaction at the post-high school level. Viewing shorter video segments is linked to reducing extraneous cognitive load in middle-level classrooms (Slemmons et al., 2018). Segmenting chunks of cognitive information and incorporating them into existing student schemas supports content mastery before subsequent teacher instruction (Long et al., 2016; Lo, 2020).

Other researchers have elucidated the frustration of students who would benefit from the opportunity to ask questions in real time or receive instructor clarification of materials presented in the asynchronous format familiar to the approach (Hotle & Garrow, 2016; Lo, 2020; Schultz et al., 2014). Students who view the content alone without the opportunity for targeted review and scaffolded practice result in "an illusion of skill acquisition" (Bernholt et al., 2019), which does not elevate the flipped classroom approach over other common passive direct instructional teaching approaches. Strayer (2012) concluded that student frustration would increase and comprehension would decline without appropriate guidance by teaching personnel. Students usually favour using class time for learner-centred activities facilitated by the classroom teacher (Kim et al., 2016; O'Flaherty & Phillips, 2015; Seery, 2015). With the bulk of introductory content covered in carefully selected pre-training activities, class time can be used to complete laboratory experiments, participate in in-group discussions, and complete problem sets in small groups. Students who find classes more enjoyable remain more fully engaged and responsive to the learning process.

#### 2.3.4.2 Teacher creation of digital material for flipped classroom learning approach

The front-end preparation of digital materials before implementing the flipped classroom learning approach is a detractor for many who would likely embrace the method (Kim et al., 2014; Lage et al., 2000; Leo & Puzio, 2016; Roehl et al., 2013). Larson and Linnell (2023) posit teachers' workload decreases over time; however, the initial development of pre-class instruction increases by as much as 127% over preparation time for a traditional course the first time implementing the flipped classroom learning approach.

Wanner and Palmer (2015) reported that over 50% of teachers within a sample of 47 expressed a high degree of pressure to incorporate flipped teaching without additional administrative support or training. The considerable work required upfront may deter many instructors from fully implementing the flipped classroom approach over traditional methods, given the significant time constraints already present in their instructional practice (Ramnanan & Pound, 2019). However, a study by Sit and Brudzinski (2017) found that 99% of teachers sampled from 453 teachers who had adopted a flipped model would continue to utilize it in future coursework.

In addition, teachers may not be familiar with the technology necessary to create audiovisual lessons or have the administrative support required to execute the flipped classroom approach. As the technology used for presenting information gets smarter, faster, better, and cheaper, educators will be forced to learn and access more of these tools (Roehl et al., 2013). A study by Owston et al. (2019) reported that a higher percentage of teachers, in their research, self-reported their skills in standard educational technology as either proficient or advanced; however, less than 50% claimed to be proficient in technology specific to their fields, such as the use of electronic databases and smart boards.

# CHAPTER THREE

# METHODOLOGY

## 3.0 Overview

This chapter presents the research approach and design. It also presents population, sample and sampling procedure, the research instruments, validity and reliability of the instruments as well as the data collection procedure, analysis and ethical consideration are presented in this chapter.

## 3.1 Research Approach

The approach to this study was quantitative. The use of a single-group pre- and post-test design, along with statistical analyses such as paired sample t-tests, indicates a quantitative orientation. This approach involves collecting numerical data to measure changes in students' understanding of electron configuration before and after the implementation of the flipped classroom approach.

While the study incorporates some qualitative elements, such as student perceptions and experiences gathered through Likert-scale surveys, the general approach leans toward a quantitative approach.

## 3.2 Research Design

This investigation employed a single-group pre-test and post-test action research design. Action research, according to Van de Ven, Boardley and Chandler (2022), is a democratic and participatory methodology that aims to generate valuable data for the development of acceptable human objectives. Ahmed, (2020) characterises action research as a critical collaborative inquiry that engages in participatory issue resolution and undergoes public self-evaluation. It is a research approach that focuses on a specific problem and aims to formulate an action plan to address or resolve the identified problem.

Figure 3 presents the design for this research, which encompasses the three phases of action research.

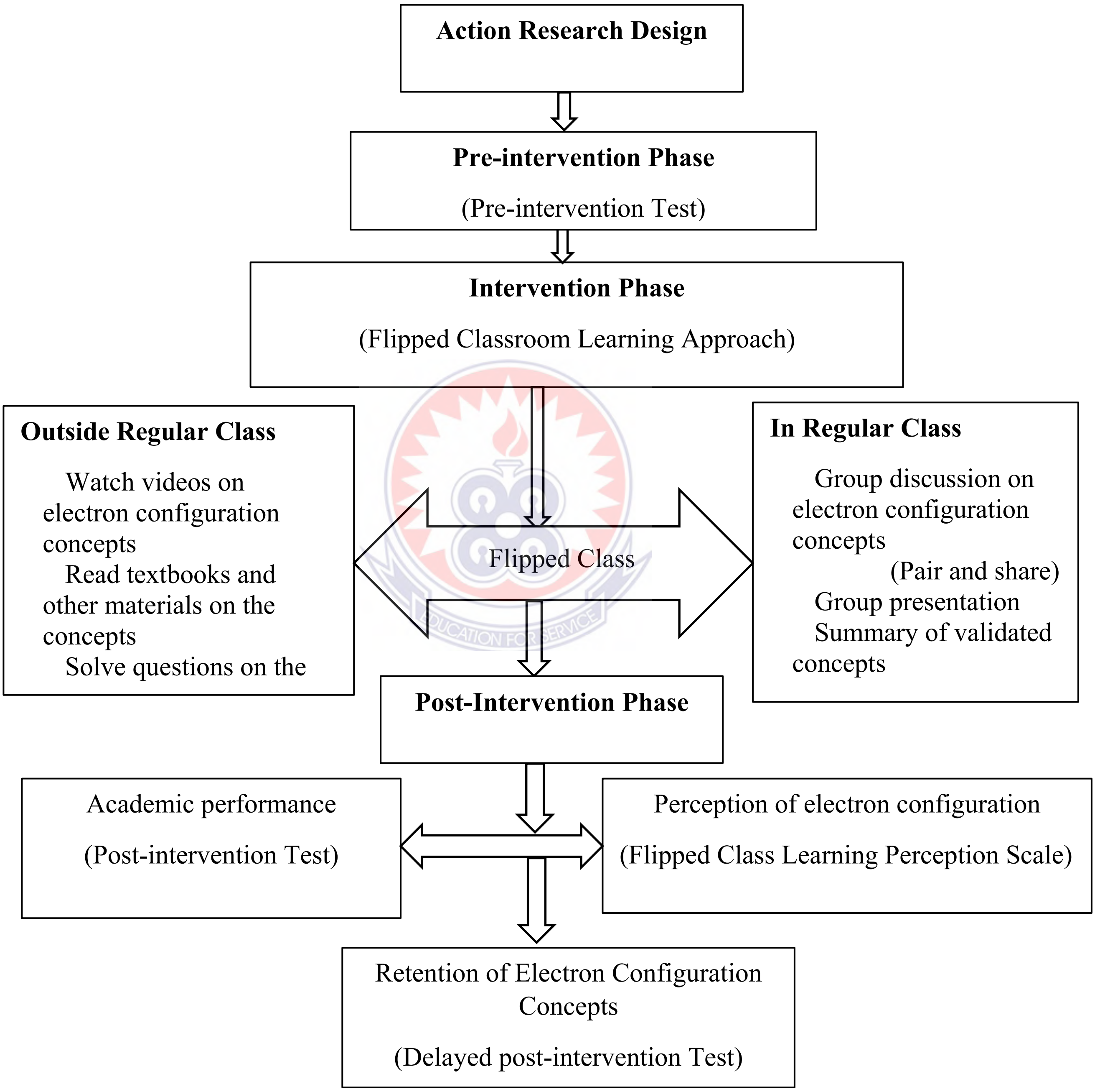


**Figure 3: An action research study navigation scheme using flipped learning**

From Figure 3, the design categorizes the action research into three phases. The first phase, the pre-intervention phase, marked the identification of the students' difficulties in understanding the concept of electron configuration. This was ascertained through the pre-intervention test. The second phase was the intervention phase, where the flipped classroom learning approach was implemented to teach the concept of electron configuration, taking into consideration the students' conceptual difficulties in understanding the topic. The last phase was the post-intervention phase, where students' academic performance, retention, and perception of electron configuration concepts were determined by the post-intervention test, delayed post-intervention test, and flipped classroom learning perception scale, respectively.

The decision to adopt a single-group pre-test and post-test action research design for this study was motivated by the objective of addressing a specific challenge faced by the students of MSHTS related to electron configuration (EC). The study employed the flipped classroom learning (FCL) approach as an intervention strategy. The participation of MSHTS students in this study was encouraged because of their conceptual knowledge and performance in the area of electron configuration. The challenges associated with filling electrons into orbitals and the numerous applications of electron configuration in chemistry served as the driving factors for their involvement. The researcher collaborated with these high school students by developing flipped classroom lessons specifically designed for electronic configuration.

The intact class of SHS 2, representing the entire students of this respective grade level, was deemed suitable for the action research. The evaluation of the study's subject was based on the outcomes of various activities conducted both inside and outside the classroom. To assess the students' performance in relation to their prior understanding of electron configuration, the researcher administered a pretest. Following the pre-intervention phase, the students were introduced to the intervention phase, during which they were taught using the flipped classroom learning approach for a duration of four weeks. Subsequently, a post-intervention phase was conducted, comprising a post-test to measure the students' performance level in electron configuration and a perception questionnaire.

This study aimed to enhance the performance and conceptual understanding of electron configuration among science students at MSHTS. Quantitative methods were employed to collect and analyze data from three tests: the Electron Configuration Pre-intervention Test (ECPre-T), the "Electron Configuration Post-Intervention Test (ECPost-T), and Electron Configuration Delayed Post-Intervention Test (Delayed ECPo:st-T). These tests were used to evaluate the effectiveness of the flipped classroom learning approach in improving students' performance in electron configuration.

### 3.3 Population

When conducting a study, there are two types of populations to consider: the accessible population and the target population. Tekpor (2019) explains that researchers gather and research information from the target population, which is the group of cases they want to generalize about. On the other hand, Cook et al. (2022) explained the accessible population as the predetermined standards available to the researcher as potential study subjects. In this particular study, the target population consisted of all SHS 2 students who study chemistry in senior high schools within the Mfansteman municipality. This includes the four public senior high schools in the area, with a total student population of about 6,780. Meanwhile, the accessible population for this study comprised all 234

SHS 2 students, regardless of gender, who were studying chemistry as a subject in MSTHS.

### 3.4 Sample and sampling procedure

A sample is a real representation of the population that is chosen for a study's observation (Mishra & Alok, 2022). The size of the sample must be carefully determined, considering various factors such as the researcher's objectives, the significance of the research, and the available resources (Lakens, 2022). In this particular study, a purposive sampling technique was utilized to select 45 students from a single class (in-tact class), consisting of both male and female participants. These students were selected due to their prior knowledge of chemistry, particularly electron configuration, which is the main focus of this study. As action research, the difficulty in understanding electron configuration concepts among the students was characteristic of the selected intact class for this study, hence, the use of purposive sampling technique.

### 3.5 Research Instruments

The following research instruments were employed in this study.

a. 'Electron Configuration Test' (ECPre-T, ECPost-T and Delayed ECPost-T)
b. Flipped Classroom Learning Electron Configuration Perception Scale (FCLECPS)

#### 3.5.1 Electron configuration tests items

The electron configuration tests (ECPre-T, ECPost-T and delayed ECPost-T) were constructed by the researcher to collect data on the performance of the students in electron configuration. The test instrument was formed based on the objectives of the topic. The test questions were taken from formal examinations that the West African

Examination Council had administered since 2010 and other formal examination bodies. There were three divisions on the instrument; the participant's biographical information and general information regarding the purpose of the test. Section A comprised 30 multiple-choice items constructed to collect data on students' performance. Any correct option earned one mark. The items in Section B, had 10 questions provided with a blank space for students to provide a correct scientific response to fill-in the blank space provided. This segment in the test focused more on students' ability to use concepts to write properly about an atom's electronic configuration using a basic understanding of electron energy levels, the origin of orbitals (sublevels), and rules and principles for filling them with electrons.

The 'Electron Configuration Post-Intervention Test' (ECPost-T) and the 'Electron Configuration Delayed Post-Intervention Test' (Delayed ECPost-T) were modified forms of the Electron Configuration Pre-intervention Test (ECPre-T). The ECPost-T and Delayed ECPost-T were modified after the ECPre-T was pilot tested and its reliability coefficient determined.

### 3.5.2 Flipped classroom learning electron configuration perception scale (FCLECPS)

A 5-point Likert scale perception questionnaire was developed by the researcher; titled the Flipped Classroom Learning Electron Configuration Perception Scale (FCLECPS). The questionnaire was used to reflect on the perceptions of students after their engagement with the flipped classroom learning intervention. The questionnaire instrument was categorized under the following scale; flipped classroom experience with 10 items; teacher support with 5 items; learning environment with 4 items; and academic achievements in electron configuration with 3 items.

Students were expected to react to these items using 5 points of the Likert scale: strongly agreed (SA), Agree (A), Neither Agree nor Disagree (N), Disagree (D), and Strongly Disagree (SD). Positively worded perception items were graded as Strongly Agree = 5, Agree = 4, Neither Agree nor Disagree = 3, Disagree = 2 and Strongly Disagree = 1. Conversely, negatively worded perception items were graded as Strongly Disagree = 5, Disagree = 4, Neither Agree nor Disagree = 3, Agree = 2 and Strongly Agree = 1.

### 3.6 Validity of the research instruments

To determine the effectiveness of a research tool, one must ascertain its ability to accurately capture the variables it was designed to track, which is referred to as validity. Validity can be broken down into four categories, including content validity, face validity, criterion-related validity, and construct validity. The researcher's supervisor in the Department of Chemistry Education, University of Education, Winneba, along with four experienced chemistry teachers in senior high schools, thoroughly discussed and validated the face and content validity of the instruments in this study. The materials, including the electron configuration test instrument and research questionnaire on student perceptions, were carefully reviewed, and necessary adjustments were made based on the feedback received. Pre-testing was also conducted to confirm the suitability of the content and the clarity of the test items. Additionally, the creation of a table of specifications (TOS) ensured the validity of the test instrument’s content. The validators provided feedback, which was used to revise the instruments and materials to ensure their efficient validity.

### 3.7 Reliability of the research instruments

According to Joppe (2000), reliability refers to outcomes being consistent over time. knowledge, A research tool is deemed reliable if the results can be replicated using a similar methodology. The ability of an experiment, test, or any measuring process to produce consistent results after numerous attempts is known as reliability (Patton, 2007). The reliability of the electron configuration test instrument and the research questionnaire on students' perceptions has been determined using reliability coefficients.

The questionnaire's integrity was measured using the inter-item consistency reliability test. To ensure the accuracy of the perception questionnaire instrument, a pilot test was conducted on a small group of 20 participants who shared similar characteristics with the study group but were not part of the study's participants. An internal consistency estimate of reliability was used to determine the instrument's reliability. The questionnaire's dependability was measured, and it was found to have a reliability value of 0.774, meeting the suggested criterion by Taherdoost (2019).

A test-retest approach was used to measure the reliability of the 'Electron Configuration Pre-intervention Test' (ECPre-T) after it was trial-tested. This involves administering the same test twice within a 24-hour interval to a group of individuals (Cohen, Swerdlik, & Sturman, 2013). A reliability correlation coefficient of 0.710 was obtained after the test-retest approach. The post-intervention test and the delayed post-intervention test were then modified from the pre-intervention test to avoid threats to the internal validity of the test items.

### 3.8 Data Collection Procedure

Data collection was done in three stages namely pre-intervention, intervention and post-intervention.

#### 3.8.1 Pre-intervention phase

In this phase, the researcher being acquainted with the required knowledge, trained one co-opted chemistry instructor for a week. The co-opted chemistry teacher was tutored on the implementation of flipped classroom learning approach. Within that period, the researcher constantly reminded the study group to revise their notes on electronic configuration, which they were earlier taught through the traditional teaching approach, to prepare them for the pre-intervention test. After eleven days of revision, the co-opted chemistry teacher assisted the researcher in organizing the participants to sit for the pre-intervention test. The test lasted for fifty (50) minutes. The pre-intervention strategy was used to ascertain the study group's pre-existing understanding of the electron configuration concepts since they had already been taught the topic in class.

The researcher, with the assistance of a video editor, created the electron configuration pre-recorded video companion that covers the same content as the Ghana Education Service elective chemistry syllabus. The researcher's supervisor validated the Electron Configuration (EC) video companion and six other experts in chemistry education at the second cycle level. The EC video companion was designed to function offline, as the study participants were all boarding students who had limited access to personal electronic devices, and the school's laboratory computers were experiencing internet connectivity issues.

The EC video companion was installed on the computers in the ICT laboratory for students to access its content outside of their regular classroom schedule. Upon watching the videos, the students were given tasks to complete and asked to submit their solutions during in-class engagement. It was emphasized that being prepared for class was extremely emely hard and students were encouraged to understand the video lessons in order to participate in class activities and discussions. The EC video companion for this study consists of three lessons, each containing approximately three videos. According to Wagner and Urhahne (2021), videos used in a flipped classroom should not exceed 20 minutes to ensure students remain engaged and attentive.

### 3.8.2 Intervention phase

The implementation of the flipped classroom learning approach took a period of three weeks. The researcher and the co-opted chemistry teacher worked extremely hard and intensively to achieve the purpose of the study. flipped-centered classroom learning approach is an innovative instructional method of teaching designed to be learner-centered, in which teaching and learning or instructional content are developed outside the classroom. Learners are introduced to learning material before class, with classroom time being used to deepen understanding through discussion with peers and problem-solving activities facilitated by the teacher.

The intervention in this study was administered to a cohort of forty-five students in the first semester of the 2022–2023 academic year. Students were exposed to the content of the developed flipped classroom approach video companion installed in the school's computer laboratory. An electron configuration flipped classroom learning lesson plan was developed before the intervention as part of the flipped classroom learning didactic instructions. Flipped classroom learning approach video lessons and in-class resources for each week were developed following the lesson transcript as shown in Table 1.

**Table 1: Week 1 out-of-class activities in learning electron energy levels of atom**

| Teacher Activities | Student Activities |
|---|---|
| Assigned pre-lesson reading (electron energy levels) | Read assigned material, take notes, and highlight important concepts. |
| I ensured the videos were installed on the computers. | Students visited the ICT Lab to watch video content. |
| I supervised students as they watched video content privately. | Students participated actively in learning the video content |

From Table 1, both the teacher and the students were assigned activities to ensure learning of the electron energy levels of an atom. A screenshot of a section of the first flipped classroom lesson's video on an atom's electron energy level is presented in Figure 4

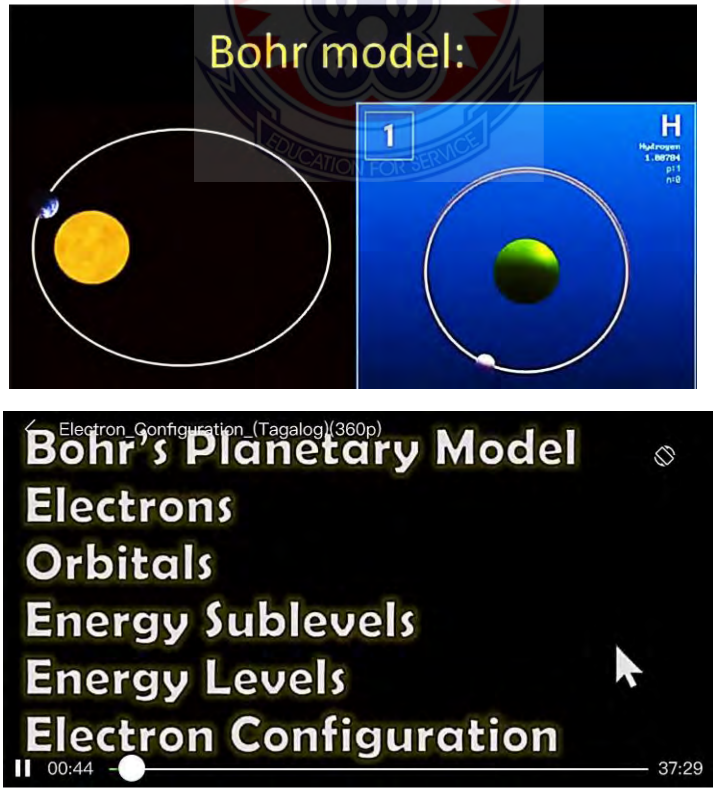


**Figure 4: Screensnap of a section of the first flipped classroom lesson's video on an atom's electron energy levels**

In Figure 4, the video shows Bohr's planetary model of an atom indicating the electron, the orbital, energy sublevels, energy levels and the electron configuration.

As a follow-up to the out-of-class activities in learning electron energy levels of an atom, Table 2 presents week one's in-class activities lesson regarding an atoms and electron energy levels.

**Table 2: Week 1 in-class activities lesson plan regarding electron energy levels of atom**

| **Teacher activity** | **Student activity** |
|---|---|
| Facilitated recap discussion on pre-lesson reading | Engage in discussion, ask questions, and clarify misconceptions |
| Facilitated interactive presentation on electron energy levels | Group presentations on electron energy levels during class |
| Facilitated hands-on activities (model building or simulations) | Engage in hands-on activities and explore electron energy levels |
| Sample seatwork:<br>Given an atom with a certain number of electrons, construct a model showing the distribution of electrons in different energy levels. | Students participate actively as teacher performs the activities |
| Facilitate simulation of absorption and emission of photons by electrons transitioning between energy levels and discuss the relationship to spectral lines | |

As shown in Table 2, both the teacher and students participated in activities that led to the learning of an atom's energy levels. This aspect of the flipped classroom learning approach was carried out during in-class sessions. This is presented in Table 3.

**Table 3: Week 2 out-of-class activities in learning atomic orbitals.**

| Teacher activity | Student activity |
|---|---|
| Assigned video lesson on atomic orbitals | Watch video lesson, take notes, pause to reflect and conceptualise the video content |
| Supervised students as they watched video content privately | Students actively engaged in watching video content to maximise understanding of atomic orbitals |

As indicated in Table 3, the aim of the activities was to ensure adequate understanding of the concept of atomic orbitals among the students. The video content was meant to facilitate students' understanding of the concepts.

Figures 5, 6, 7, 8, 9, and 10 present screen shots of video lessons showing the principal quantum numbers of atomic orbitals, the azimuthal quantum number of atomic orbitals, the magnetic quantum number of atomic orbitals, the number of orbitals associated with a sublevel, the magnetic spin quantum number of atomic orbitals, and lesson material on electron configuration, respectively.

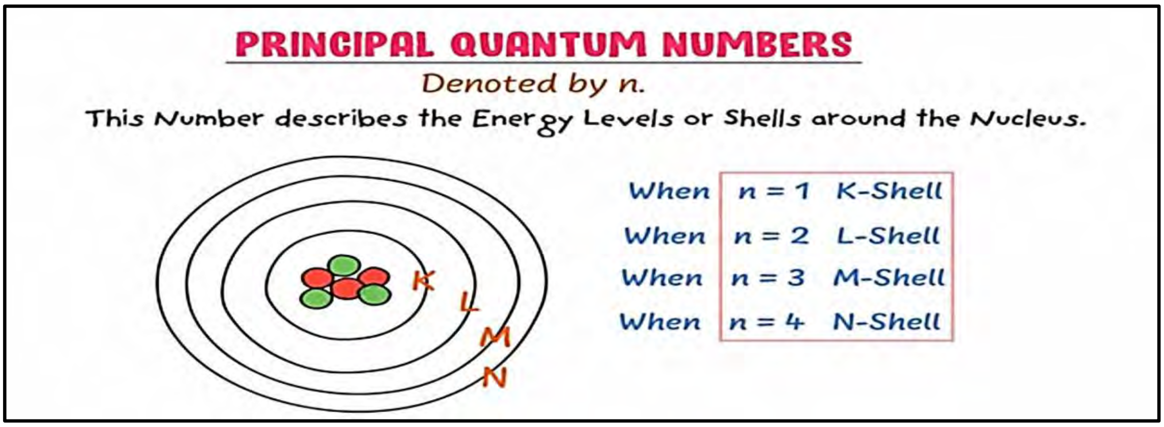


**Figure 5: Screen shot of video lesson showing the principal quantum number of atomic orbitals**

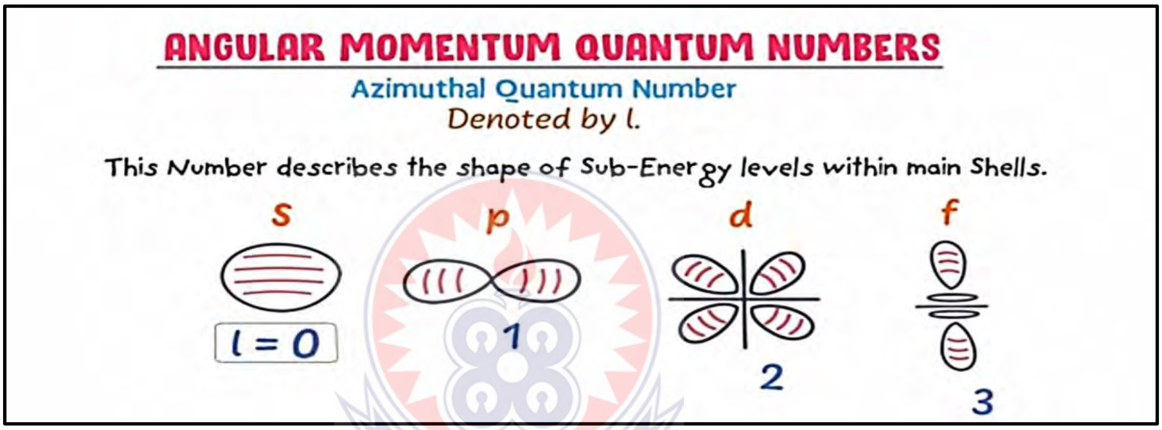


**Figure 6: Screen shot of video lesson showing the azimuthal quantum number of atomic orbitals**

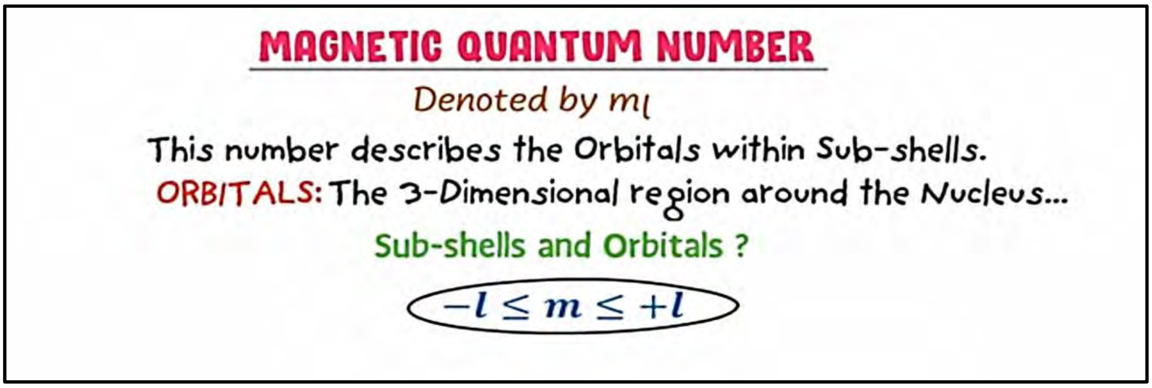


**Figure 7: Screen snap of video lesson showing the magnetic quantum number of atomic orbitals**

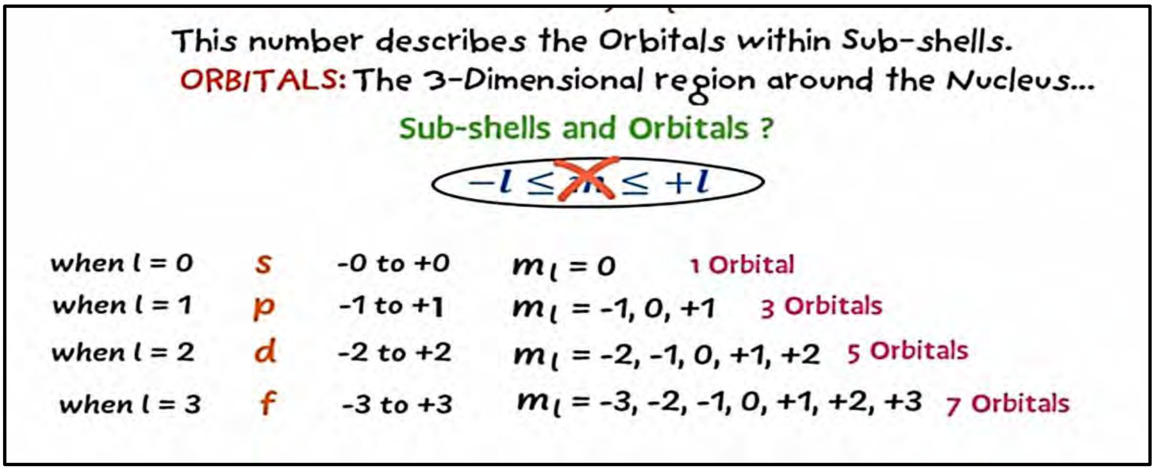


**Figure 8: Screen shot of video lesson showing the number of orbitals associated with a sublevel**

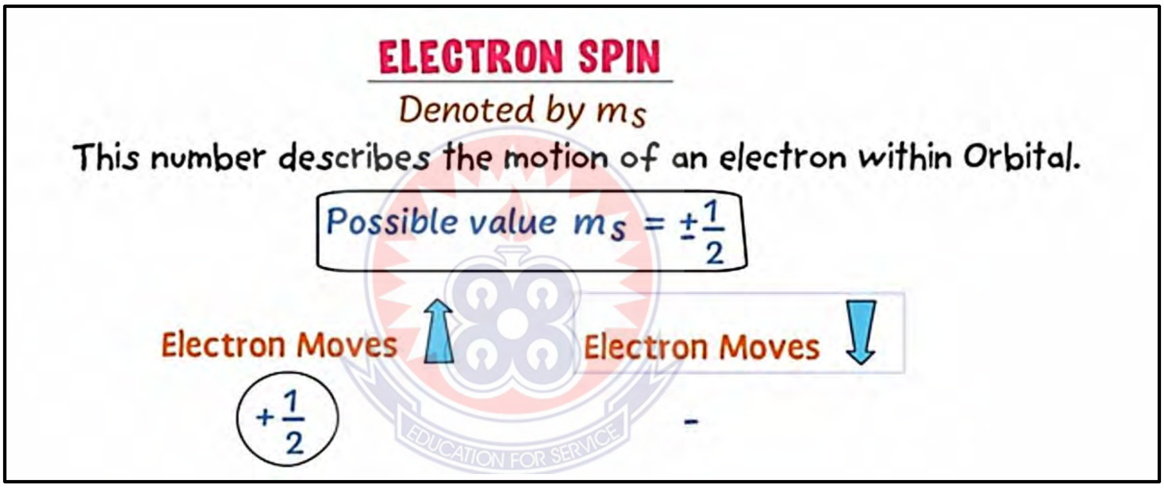


**Figure 9: Screen snap of video lesson showing the magnetic spin quantum number atomic orbital**

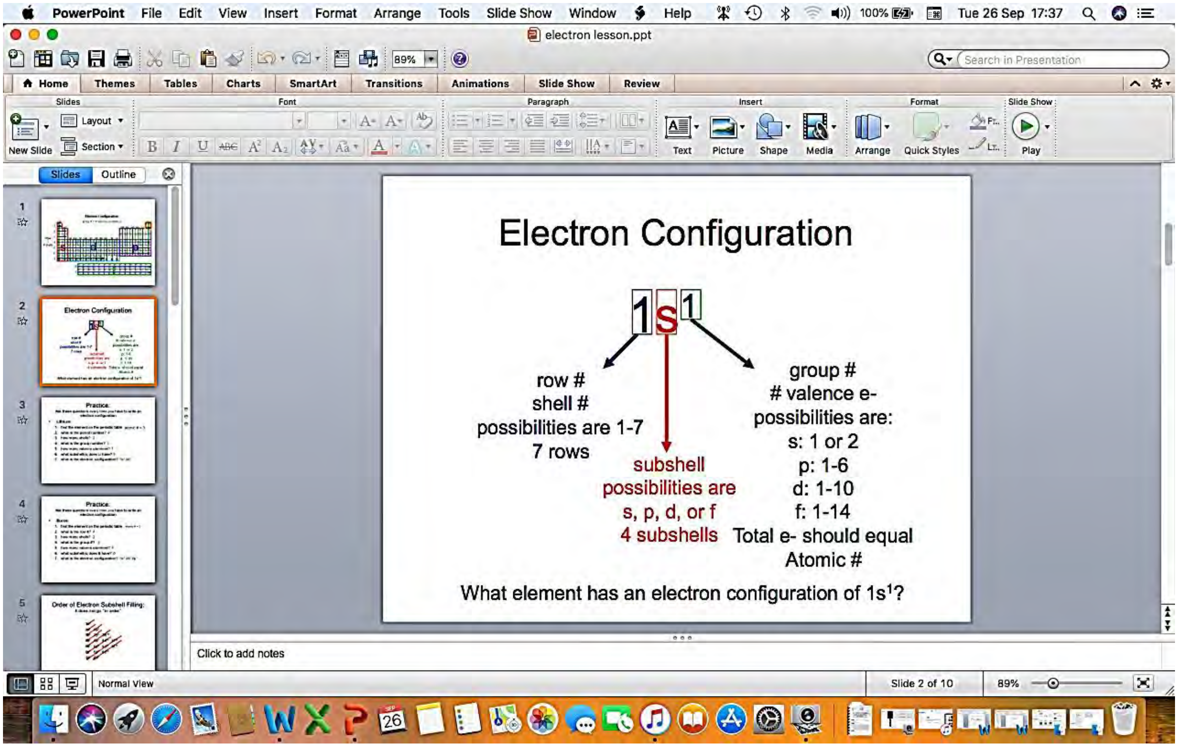


**Figure 10: Screen snap of prepared slide lesson material on electron configuration**

Figures 5, 6, 7, 8, 9, and 10 were sample screen snapshots of video lessons that facilitated the students' understanding of electron configuration concepts through the flipped classroom learning intervention.

Week two in-class activities for learning atomic orbitals among the students are presented in Table 4. The teacher activity and the student activity are indicated.

**Table 4: Week 2 in-class activities in learning atomic orbitals**

| Teacher activity | Student activity |
|---|---|
| Facilitated concept review on atomic orbitals | Participated in concept review and asked questions |
| Facilitated group presentations on assigned orbital shapes | Group presentations on assigned orbital shapes (s, p, d, and f orbitals, including their shapes, orientations, and characteristics)<br>Discuss how their shapes relate to the probability of finding an electron in different regions. |
| Facilitated hands-on exploration of atomic orbitals | Explore and manipulate atomic orbitals that relate to concepts |

From Table 4, week two in-class activities in learning atomic orbitals are follow up activities on the out-of-class activities carried out within the schedules for that week. The focus of those out-of-class activities was on video lessons showing the principal quantum numbers of atomic orbitals, the azimuthal quantum number of atomic orbitals, the magnetic quantum number of atomic orbitals, the number of orbitals associated with a sublevel, and the magnetic spin quantum number of atomic orbitals.

Last, but not least, Table 5 presents three out-of-class activities for learning the rules and principles of filling electrons into atom energy levels.

**Table 5: Week 3 out-of-class activities for learning rules and principles of filling electrons into atom energy levels**

| Teacher activity | Student activity |
|---|---|
| Assigned video lessons and reading materials on principles and rules involved in filling electrons into atom energy levels | Read, watch videos and take detailed notes on principles and rules involved in filling electrons into atom energy levels |

As indicated in Table 5, students were engaged in reading and watching videos as well as taking detailed notes on principles and rules involved in filling electrons into atom energy levels. Screen shots of video lessons showing the various principles and rules governing the filling of electrons into atom energy levels are shown in Figures 11, 12 and 13.

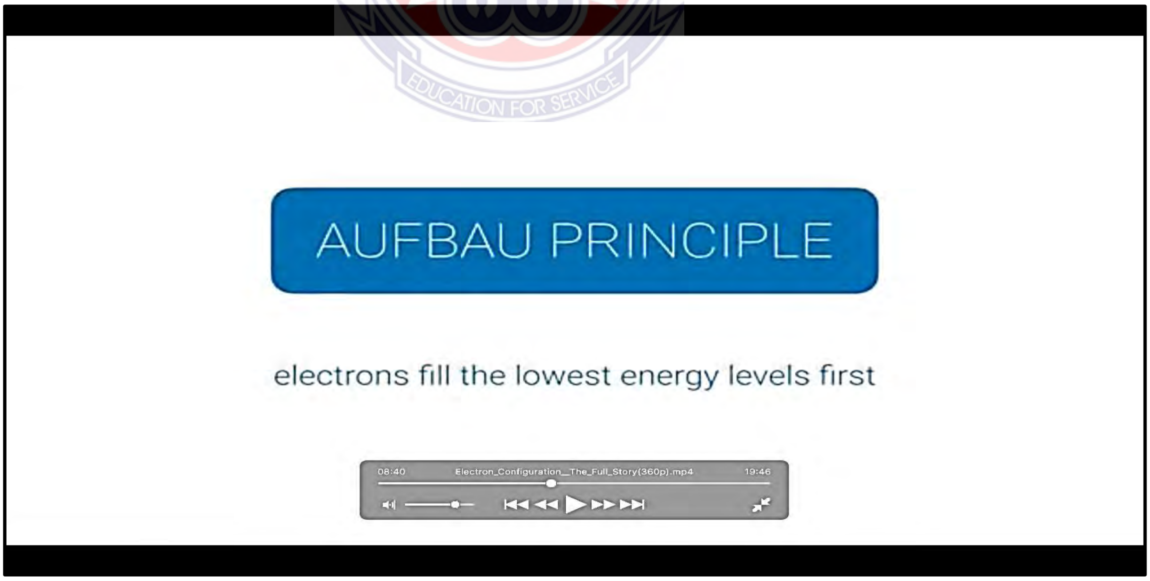


**Figure 11: Screen shot of video lesson showing the scientific definition of Aufbau's principle**

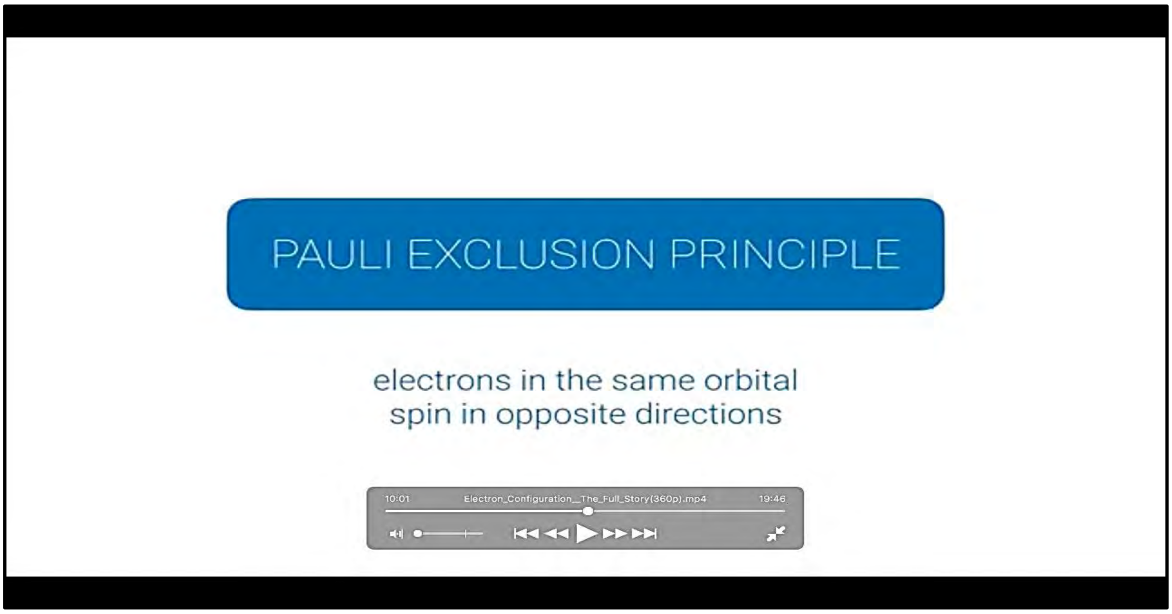


**Figure 12: Screen shot of video lesson showing the scientific definition of Pauli's exclusion principle**

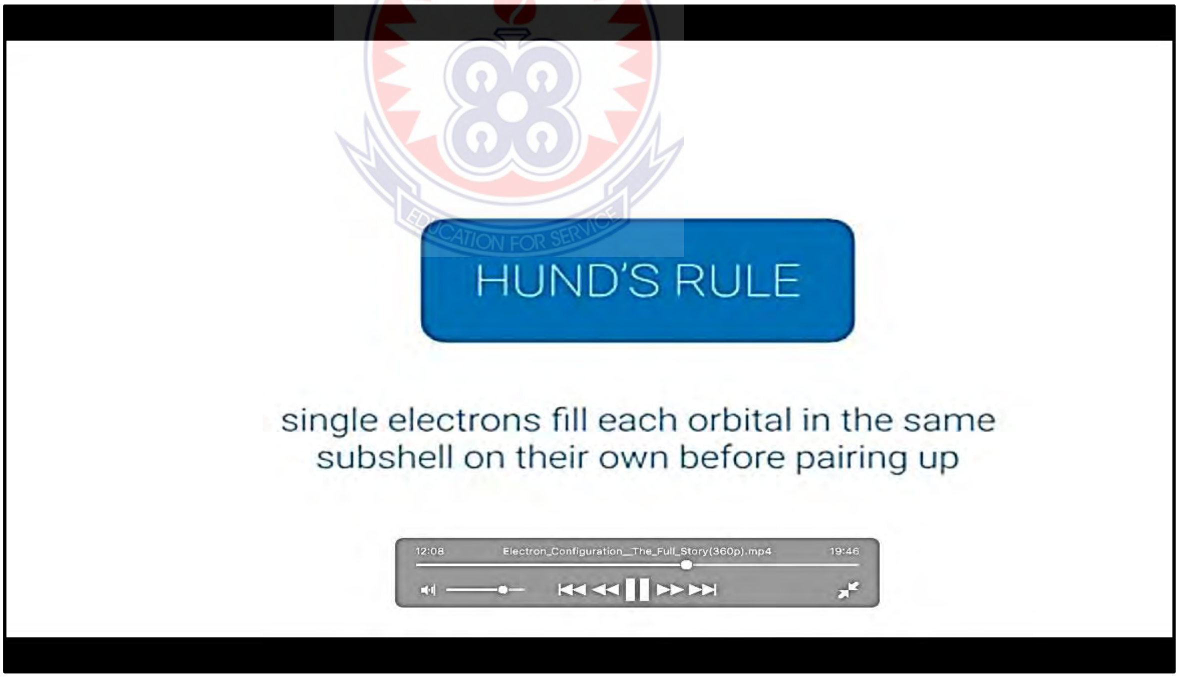


**Figure 13: Screen shot of video lesson showing the scientific definition of Hund's rule of maximum multiplicity**

As part of the out-of-class activities within the schedules of week three, students had to read, watch videos, and take detailed notes on the principles and rules governing the filling of electrons into atom energy levels, as represented in Figures 11, 12, and 13.

Table 6 shows week three in-class activities for learning the rules and principles that guide the filling of electrons into atom energy levels.

**Table 6: Week 3 in-class activities for learning rules and principles of filling electrons into atom energy levels**

| Teacher activity | Student activity |
|---|---|
| Facilitate recap of content learned clarification, and clarification of reading | Participate in discussion and seek clarification, if any, on content learned |
| learned Facilitate practice on electron filling into an atom energy level based on the principles and rules involved. | Work through practice problems and work examples |
| Facilitate formative assessment on electron filling into atoms' energy levels using worksheet | Complete assignment and receive feedback based on the worksheet |

As indicated in Table 6, the week three in-class activities for learning the principles and the rules governing the filling of electrons into atoms' energy levels were meant to consolidate and validate the appropriate concepts based on what the students learned during the out-of-class activities. As part of the in-class activities, students were formatively assessed through worksheets. Figure 14 presents one of the worksheets students were engaged on as they returned to the classroom after the out-of-class activities.

**Complete the concept map as a worksheet. Choose your answer from the word list below.**

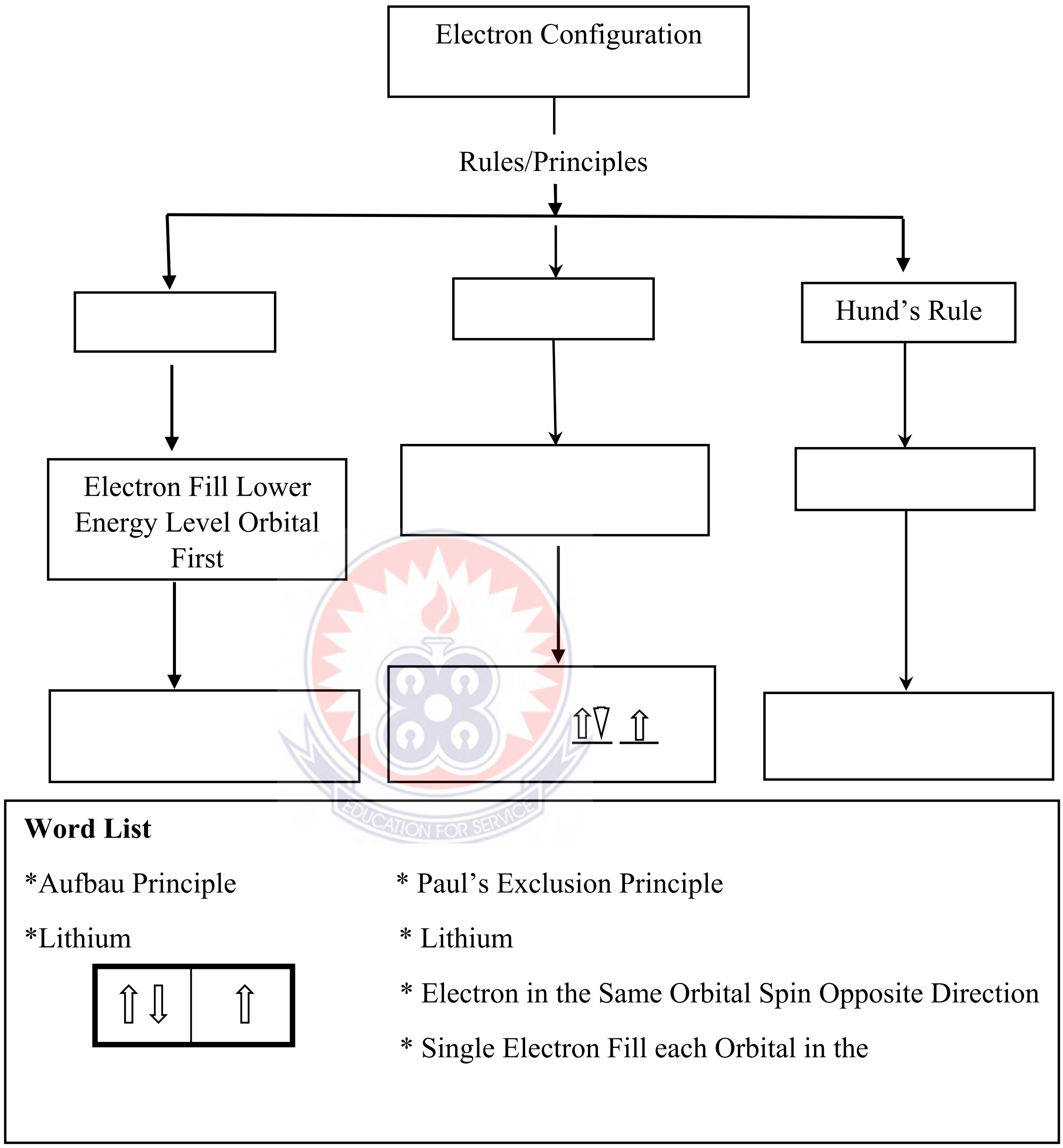


**Figure 14: Formative assessment of students' understanding of electron configuration using a worksheet.**

In Figure 14, students' conceptual understanding of the principles and rules governing the filling of electrons into atoms' energy levels was formatively assessed using the worksheet provided.

### 3.8.3 Post-intervention phase

After the intervention using the flipped learning approach, the 'Electron configuration post-test' (ECPost-T) was administered to determine the students' academic performance in electron configuration. ECPost-T usage prevented pre-test sensitization's negative effects. Pre-test sensitization, which occurs naturally when the same pre-test is used even without any intervention, causes the respondents to do better in the post-test because of prior experience (Patton 2005). To accommodate students varying levels of thinking, the post-test items being modified from the pre-test got progressively more challenging as they went along. Additionally, a delayed post-test was administered to assess the effect of the intervention on students' retention. Students were given 50 minutes to respond to the test items. Again, with the assistance of the co-opted chemistry teacher, copies of the 'Flipped Classroom Learning Electron Configuration Perception Scale' (FCLECPS) were also administered successfully for students to provide their responses to the questionnaire. This was meant to determine the students' perceptions of the flipped classroom in learning electron configuration.

### 3.9 Data Analysis Procedure

Data were analyzed with regards to the research questions. A relationship was established between the independent variable, which is the flipped classroom learning approach, on the one hand and students' academic performance, retention of electron configuration concepts, and perceptions towards electron configuration, all of which are dependent variables on the other hand.

The first research question involved the determination of participants' understanding of electron configuration concepts before the flipped classroom learning approach. To assess the open-ended questions in the diagnostic test, the researcher utilized Necor's (2018) concept-evaluating system. This particular system was chosen as it allowed the researcher to accurately evaluate and score the responses.

The students' responses were checked based on the scientific explanations to identify their levels of conceptual understanding. Students who provided answers that aligned with the validated scientific concepts were considered to have a full understanding (FU). Responses that included at least one of the components of validated scientific concepts but not all of them were classified as partial understanding (PU). If the answers were blank or unclear and did not conform to the validated scientific concepts, they were deemed to have no understanding (NU). Table 7 presents the criteria for determining the level of students' conceptual understanding of electron configuration before the implementation of the flipped classroom approach.

**Table 7: Level of students' conceptual understanding and criteria for scoring**

| Level of Understanding | Criteria for scoring |
|---|---|
| FU: Full Understanding | Responses were fully validated as scientifically correct |
| PU: Partial Understanding | Responses were partially validated as scientifically correct |
| NU: No Understanding | responses were completely scientifically incorrect |

Analyzing their responses, we assessed the level of understanding among the students. The data were then quantified using frequency counts and percentages to determine the number of respondents exhibiting each level of understanding. Therefore, the participants' preexisting knowledge of configuration was mined.

Formulated research questions 2 and 3 into hypotheses were analyzed with the aid of Microsoft Excel version 19.0. Descriptive statistics, such as frequency counts, percentages, mean scores, and standard deviation, were used to compare student performance before and after the intervention. A dependent-samples t-test was used to investigate any significant difference that existed between the pretest and post-test to determine the academic performance of the students in electron configuration after the intervention. Also, a dependent-samples t-test was used to investigate any significant difference that existed between the post-test and the delayed post-test to determine the students' retention of electron configuration concepts. The hypotheses were tested at a significance level of 0.05.

The eta squared formula was used to calculate the effect size of the flipped classroom on students' retention and performance of electron configuration concepts. The criteria for measuring the effect size, according to Cohen (1988), for interpreting the eta square value are as follows: 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect.

However, for research question 4, questionnaire items were divided into six constructs with five major themes. The themes were presented as a series of Likert-scale items. To improve reliability in the data, some items were positively worded and others negatively worded. Also, thematic items were randomly distributed to ensure students did not simply select a single response to all the items without reading them. The mean and the standard deviation were computed for each thematic item using Statistic Package for Social Science (SPSS) version 20. The results were presented using tables.

### 3.10 Ethical consideration

The researcher secured an introductory letter from the Chemistry Education Department, University of Education, Winneba. This letter was presented to MSTHS in Mankessim to request permission to engage the students as research participants in the study. The researcher also coordinated with the school's headmaster, ICT coordinator, and Head of the Science Department to schedule data collection and intervention dates. Before participating, the students were briefed about the purpose of the study and were informed that their responses to the questionnaire and test items would only be used for research purposes and that their confidentiality would be maintained. The participants' consent to the study was sought, and they were also given the option to withdraw from the study at any time without question.

To maintain anonymity, the students were instructed not to include their names or index numbers on the questionnaire or the test items. Throughout the data collection and analysis processes, the researcher ensured objectivity and avoided any influence on the participants or their responses.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.0 Overview

This chapter illustrated the results and discussion of findings obtained from the analysed data on the research questions and the corresponding hypotheses in chapter 1. The analysis of the results preceded the discussion of the findings.

## 4.1 Results

### 4.1.1 Research question one

What is the conceptual understanding of students in electron configuration before the flipped classroom learning approach?

Research question one sought to explore the prior knowledge and understanding of students in writing electron configurations of elements of the main group and transition metals before the application of the flipped classroom learning approach. The prior knowledge and level of understanding of the concepts of the respondents were analyzed in terms of the requirements of the question and classified as no understanding, partial understanding, 40, and full understanding.

Table 8 shows the levels of students' conceptual understanding of electron configuration concepts. Pre-test items of the open-ended portion of the entire test, numbering items 31 to 40, were considered in determining the students' understanding of the concepts.

**Table 8: Level of conceptual understanding of students in electron configuration**

| QI | Concepts Tested | (FU) | | (PU) | | (NU) | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | % | N | % | N | % | N | % |
| 31. | Application of Pauli's exclusion principle | 9 | 20.0 | 1 | 2.2 | 35 | 77.7 | 45 | 100 |
| 32. | Application of Hund's rule of maximum multiplicity | 20 | 44.4 | 0 | 0.0 | 25 | 55.6 | 45 | 100 |
| 33. | The period and group (family) of $_{16}S$ | 11 | 24.4 | 6 | 13.3 | 28 | 62.2 | 45 | 100 |
| 34. | The number of unpaired electrons in $_{29}Cu$ | 15 | 33.3 | 0 | 0.0 | 30 | 66.7 | 45 | 100 |
| 35. | Meaning of $5d^6$ | 6 | 13.3 | 9 | 20.0 | 30 | 66.7 | 45 | 100 |
| 36. | Electron configuration of $_{9}F^{-}$ (anion) | 11 | 24.4 | 0 | 0.0 | 34 | 75.6 | 45 | 100 |
| 37. | Electron configuration of $_{26}Fe^{+}$ (cat ion) | 7 | 15.6 | 0 | 0.0 | 38 | 84.4 | 45 | 100 |
| 38. | Ground state electron configuration of $_{24}Cr$ | 11 | 24.4 | 0 | 0.0 | 34 | 75.6 | 45 | 100 |
| 39. | Significance of the use of arrows and the letters *x, y, and z* | 2 | 4.4 | 12 | 26.7 | 31 | 68.9 | 45 | 100 |
| 40. | Assigning maximum number of electrons for *f* orbital | 12 | 26.7 | 0 | 0.0 | 33 | 73.3 | 45 | 100 |

**Key: FU (full understanding), PU (partial understanding), NU (no understanding), QI (question item). N – number of students**

According to Table 8, Section B of the pretest consisted of ten short essay-style questions. Out of all the questions, 32, 34, and 40 had the highest percentage of full understanding (FU) regarding the application of Hund's rule of maximum multiplicity, the determination of unpaired electrons in 29Cu, and the maximum number of electrons for the f orbital. A total of 20 students (44.4%) answered question 32 correctly, while 15 (33.3%) and 12 (26%) students got items 34 and 40 right, respectively.

However, as shown in Table 8, a majority of the students did not have a clear understanding of several concepts. For instance, 38 (77.7%) students did not understand the electron configuration of both cations and anions, while 35 (5.6%) students had no understanding of the application of Pauli's exclusion principle. Additionally, some students (12, or 26%) did not have a clear understanding of the ground-state electron configuration of some transition elements.

On average, among the three levels of conceptual understanding, the students who exhibited no understanding of the concepts were the majority. Few students showed full understanding, and fewer students showed partial understanding of the electron configuration concepts.

According to the research question, the study discovered that most students in the intact class who took part in the study did not possess a significant conceptual comprehension of electron configuration, regardless of the fact that their teacher had taught the topic in the traditional mode during regular class. The findings revealed that the students had more difficulties writing the electron configuration of cations and anions, as well as some transition elements, than neutral atoms belonging to the main groups.

### 4.1.2 Research question two

What is the effect of flipped classroom learning on students' performance in electron configuration?

This research question focused on determining the effectiveness of the flipped classroom approach on the students' academic performance in electron configuration within the intact class. This research question was formulated into a null hypothesis, which was tested at a 5% significance level. Thus, the null hypothesis was stated, "The flipped classroom learning has no significant effect on students' academic performance in electron configuration."

Table 9 presents the results of the dependent-samples t-test for the mean scores of the participants after the implementation of the flipped classroom learning approach. This was done by comparing the students' performance in the pre-test and the post-test. Eta squared was also calculated to determine the magnitude of the effect that flipped classroom learning has on the students' academic performance.

**Table 9: Dependent-samples t-test of the students' scores in the pre-test and post-test**

| Test | *N* | *M* | *SD* | *df* | *t* | *p* | $\eta^2$ |
|---|---|---|---|---|---|---|---|
| Pre-test | 45 | 34.67 | 13.46 | 44 | 12.46 | 0.000 | 0.78 |
| Post-test | 45 | 71.30 | 11.7 | 44 | | | |

***Significant at p < 0.05***

In Table 9, the dependent-samples t statistic was documented to demonstrate a notable difference in mean scores while also observing relatively consistent standard deviations for both sets of tests. The primary objective of this dependent-samples test was to determine the effect of the intervention by examining any changes in students' performance.

A statistically significant difference emerged in the mean scores between the pretest (M = 34.67, SD = 13.46) and the post-test (M = 71.30, SD = 11.77; t (44) = 12.46, p = 0.000). Consequently, the null hypothesis was rejected. It is worth noting that the difference in means observed between the two groups was quite substantial. Specifically, the use of the flipped classroom learning approach resulted in a significantly greater impact on students' performance in electron configuration, as evidenced by the large effect size ($\eta^2 = 0.78$). This finding suggests that the flipped classroom approach may be a highly effective method for improving student outcomes in this area of study.

#### 4.1.3 Research question three

What is the effect of flipped classroom learning on students' retention of electron configuration concepts?

The purpose of this research question was to assess the retention of students' performance in electron configuration following a flipped learning approach. This assessment was accomplished by conducting a dependent-samples t-test to compare the mean scores between the post-test and delayed post-test. This research question was formulated into a null hypothesis, which was tested at a 5% significance level. Thus, the null hypothesis was stated, as "flipped classroom learning has no significant effect on students retention of electron configuration concepts.".

The results of the dependent-samples t-test of the post-test and delayed post-test are presented in Table 10.

**Table 10: Dependent-samples t-test of the students' scores in the post-test and delayed post-test**

| Test | *N* | *M* | *SD* | *df* | *t* | *p* | $\eta^2$ |
|---|---|---|---|---|---|---|---|
| Post-test | 45 | 71.30 | 11.77 | 44 | 3.31 | 0.001 | 0.190 |
| Delayed post-test | 45 | 80.00 | 15.22 | 44 | | | |

***Significant at p < 0.05***

There is a statistically significant difference in the mean scores between the post-test (M = 71.30, SD = 11.77) and the delayed post-test (M = 80.00, SD = 15.22; t (44) = 3.31, p = 0.001), as reported in Table 10. In the context of the null hypothesis, which stated, "The flipped classroom learning has no significant effect on students' retention of electron configuration concepts," the findings contradict the null hypothesis; therefore, it was rejected. With a statistically significant difference between the post-test and delayed post-test scores, it is concluded that flipped classroom learning does have a significant effect on students' retention of electron configuration concepts. The substantial disparity in average scores observed between the post-test and delayed post-test, along with the effect size ($\eta^2$) value of 0.19, offers a thorough insight into the impact of implementing flipped classroom learning on the students' ability to retain the electron configuration concepts. With an effect size of 0.19, the magnitude of the effect is considered significant.

Consequently, the study found that flipped classroom learning does have a significant effect on students' retention of electron configuration concepts. As students in this study flipped their classroom lessons in electron configuration, it led to the retention of concepts learned.

### 4.1.4 Research question four

What are the students' perceptions of the flipped classroom learning approach to electron configuration?

This research question aimed to conduct a comprehensive and equitable inquiry into students' perceptions towards the implementation of flipped classroom learning as a remedial intervention for addressing the issue of low academic performance in electron configuration. Moreover, the research question also aimed to underscore students' subjective experiences and opinions about the flipped classroom learning approach when learning electron configuration. It sought to gather data on their experiences, assess their satisfaction, identify both challenges and benefits, and gain insights for potential improvements in the teaching method. The findings were demonstrated through four categories that included the experience of flipped classroom learning (FCL), teacher support (TS), learning environment (LE), and academic achievement (AA) in electron configuration while implementing the flipped classroom learning approach. These categories were presented in Table 11.

**Table 11: Themes that assessed students' general perception of the flipped classroom approach**

| Construct | N | M | SD |
|---|---|---|---|
| Flipped Classroom Experience | 45 | 4.47 | 0.68 |
| Teacher Support | 45 | 4.43 | 0.78 |
| Learning Environment | 45 | 4.33 | 0.85 |
| Academic Achievement in Electron Configuration | 45 | 4.52 | 0.55 |

Mean score greater than 3.5 represent a favourable perception of the flipped classroom by the students. Meanwhile, for mean score value less than indicates students' unsuitable perceptions. As indicated in Table 11, the results showed that of all the themes that were assessed on the students' perceptions of flipped classroom learning towards electron configuration, the means were higher based on the five-point Likert scale. The mean for each theme was more than three on the scale of one to five. Generally, the overall assessment of the four themes revealed that the students had a favourable perception of the flipped classroom learning towards electron configuration. The consistency in ratings across these items underscores the students' overwhelmingly positive perceptions of the flipped classroom approach, highlighting their endorsement and optimism regarding its applicability and effectiveness not only in electron configuration but in other academic domains as well.

A detailed analysis of each of the themes was done, and the results are presented as follows. Table 12 presents the results that indicate the students' experience of the flipped classroom learning towards electron configuration.

**Table 12: Flipped Classroom Experience**

| SN | Items | N | M | SD |
|---|---|---|---|---|
| 1 | I was comfortable using technology (e.g., pre-recorded videos,) in the flipped classroom approach for learning electron configuration. | 45 | 4.53 | 0.66 |
| 2 | The flipped classroom method provided me with enough time to prepare for class activities related to electron configuration. | 45 | 4.24 | 0.80 |
| 3 | The flipped classroom method made it easier for me to ask questions and get clarifications about electron configuration. | 45 | 4.56 | 0.55 |
| 4 | The flipped classroom method helped me to become more independent and self-directed in my learning of electron configuration. | 45 | 4.49 | 0.70 |
| 5 | The flipped classroom method provided me with more opportunities to practice and apply electron configuration concepts. | 45 | 4.47 | 0.70 |
| 6 | The flipped classroom method made it easier for me to keep up with the pace of the electron configuration course. | 45 | 4.38 | 0.65 |
| 7 | The flipped classroom method allowed me to learn electron configuration at my own pace and in my own time. | 45 | 4.49 | 0.66 |
| 8 | The flipped classroom method provided me with a variety of resources to learn electron configuration (e.g., videos, readings). | 45 | 4.56 | 0.73 |
| 9 | The flipped classroom method increased my confidence in understanding electron configuration concepts and solving related problems. | 45 | 4.58 | 0.72 |
| 10 | The flipped classroom method was more engaging than conventional classroom instruction for learning electron configuration. | 45 | 4.38 | 0.65 |

From Table 12, students exhibited a high level of comfort with technology, particularly with pre-recorded videos, within the context of the flipped classroom approach (M = 4.53, SD = 0.66). A relatively low standard deviation indicated a moderate level of agreement. The instructional method also afforded students ample time for preparation concerning electron configuration (M = 4.24, SD = 0.80). Moreover, students found it convenient to ask questions and seek clarifications about electron configuration (M = 4.56, SD = 0.54). A low standard deviation signified inclusive strong agreement. Again, the flipped classroom approach significantly promoted students' independence and self-directed learning in the context of electron configuration (M = 4.49, SD = 0.70). This pedagogical approach also provided students with increased opportunities to practise and apply electron configuration concepts (M = 4.47, SD = 0.69). This approach further facilitated students in keeping pace with the electron configuration course (M = 4.38, SD = 0.65). Notably, students had the flexibility to learn electron configuration at their own pace and at times convenient for them (M = 4.49, SD = 0.66). Additionally, this approach offered a diverse range of resources for learning electron configuration, including videos and readings (M = 4.56, SD = 0.73). Consequently, students reported an increase in confidence in their understanding of electron configuration concepts and their ability to solve related problems due to the flipped classroom learning experience (M = 4.58, SD = 0.72). Furthermore, the flipped classroom approach was perceived as more engaging than conventional classroom instruction for learning electron configuration (M = 4.38, SD = 0.65).

Results regarding student perceptions of teacher support in the context of the flipped classroom approach for learning electron configuration are presented in Table 13.

**Table 13: Teacher Support**

| SN | Items | N | M | SD |
|---|---|---|---|---|
| 1 | The teacher provided clear and concise instructions on how to use the flipped classroom approach for learning electron configuration. | 45 | 4.64 | 0.53 |
| 2 | Teacher was able to provide classification on difficult concepts during the flipped classroom activity | 45 | 4.40 | 0.78 |
| 3 | The teacher provided prompt and useful feedback on my progress in learning electron configuration through the flipped classroom approach. | 45 | 4.18 | 0.91 |
| 4 | Instructor was able to expand on pre-recorded lesson videos and pre-reading material during in-class face-to-face lesson | 45 | 4.49 | 0.97 |
| 5 | The teacher provided adequate resources and materials to support my learning of electron configuration through the flipped classroom approach. | 45 | 4.44 | 0.69 |

From the results in Table 13, students reported that they received clear and concise instructions on how to navigate the flipped classroom approach to learning electron configuration (M = 4.64, SD = 0.53). Furthermore, the students were of the view that the teacher effectively clarified challenging concepts during the flipped classroom learning activities (M = 4.40, SD = 0.78). While the teacher provided prompt and valuable feedback on students' progress in learning electron configuration, the responses exhibited some variability, with (M = 4.18, SD = 0.91) indicating a relatively high standard deviation. Again, a good number of the students indicated that the instructor successfully expanded upon pre-recorded materials and pre-reading resources in face-to-face sessions that supported their learning of electron configuration through the flipped classroom approach (M = 4.49, SD = 0.97). Lastly, the provision of adequate resources and materials to support students' learning of electron configuration was rated highly (M = 4.44, SD = 0.69)

Table 14 presents results regarding students' perceptions of the learning environment in the context of the flipped classroom approach for learning electron configuration.

**Table 14: Learning Environment**

| SN | Items | N | M | SD |
|---|---|---|---|---|
| 1 | The flipped classroom approach provided a comfortable and supportive learning environment for me to learn electron configuration. | 45 | 4.04 | 1.02 |
| 2 | The flipped classroom approach allowed me to collaborate and engage in discussions with my peers while learning electron configuration. | 45 | 4.58 | 0.66 |
| 3 | The flipped classroom approach allowed me to be more independent and take ownership of my learning of electron configuration. | 45 | 4.27 | 0.84 |
| 4 | The classroom arrangement (positioning of the chairs for group activity) was conducive for the flipped classroom activity. | 45 | 4.44 | 0.89 |

In Table 14, the results were presented concerning students' perceptions of the learning environment within the context of the flipped classroom approach for learning electron configuration. The first item reflected that students generally perceived the learning environment as moderately comfortable and supportive (M = 4.04, SD = 1.021) with a relatively high standard deviation, suggesting variability in their responses. Some students might have found it very comfortable and supportive, while others may have had a different experience. The second item indicated strong students' perceptions of the flipped classroom approach as conducive to collaboration and peer engagement (M = 4.58, SD = 0.657). The third item showed that students, on average, found the approach moderately effective in fostering independence and taking ownership of their learning (M = 4.27, SD = 0.84) However, the higher standard deviation indicates a broader range of responses, signifying that some students might have felt more independent in their learning approach than peer engagement. The fourth item conveyed that students, on average, perceived the classroom arrangement as moderately conducive to the flipped classroom approach (M = 4.44, SD = 0.89), signifying variations in their perceptions. These findings provide insights into students' varied perceptions of the learning environment within the flipped classroom approach for learning electron configuration, with some aspects being more strongly endorsed than others.

Table 15 illustrates the results regarding students' perceptions of their academic achievement in the context of the flipped classroom approach for learning electron configuration.

**Table 15: Academic Achievement in Electron Configuration**

| SN | Items | N | M | SD |
|---|---|---|---|---|
| 1 | The flipped classroom approach helped me develop better time management and study skills for learning electron configuration. | 45 | 4.51 | 0.55 |
| 2 | The flipped classroom approach was an effective way to learn electron configuration. | 45 | 4.51 | 0.55 |
| 3 | The flipped classroom approach improved my academic achievement in electron configuration. | 45 | 4.51 | 0.55 |

Table 15 presented the results pertaining to students' perceptions of their academic achievement within the context of the flipped classroom approach for learning electron configuration. All three items in this table produced identical average mean score and standard deviations (M = 4.51, SD = 0.55), signifying a high degree of agreement among the students regarding the effectiveness of the flipped classroom approach in enhancing their academic achievement and serving as an effective means of learning electron configuration. The uniformity in the mean score across these items indicated a strong and consistent perception among the students that the flipped classroom learning approach positively impacted their academic achievement and functioned as an effective approach for learning the subject. These findings underscored the positive effect of the flipped classroom learning approach on students' academic performance and aligned with their favourable perceptions of its effectiveness as a learning method for electron configuration

## 4.2 Discussion of Findings

### 4.2.1 Students' conceptual understanding of electron configuration

The findings of the study, particularly concerning the conceptual understanding of students in electron configuration before the flipped classroom learning approach, revealed a number of issues. It is clear from the results that a significant portion of the students lacked a substantial conceptual understanding of electron configuration, despite having been taught the topic in their previous regular classes in the traditional mode. This finding underscores the seriousness of the problem and highlights the necessity for an intervention like the flipped classroom learning approach. The high percentages of "no understanding" and "partial understanding" among the students, as evidenced in the results, indicated a fundamental gap in their knowledge of electron configuration. Concepts such as Pauli's exclusion principle, Hund's rule of maximum multiplicity, and the number of unpaired electrons in various elements were key components of electron configuration, and the majority of students exhibited limited or no comprehension of these concepts.

Furthermore, the high percentage of "no understanding" for some question items, such as question item 37, which focuses on electron configuration of $_{26}Fe^{+}$ suggested that a significant portion of the students either provided incorrect responses or no responses at all, indicating a critical need for targeted intervention to address these areas of confusion.

The significant percentage of students who recorded "no understanding" in various aspects of electron configuration in the study can be attributed to several scientific reasons. Electron configuration involves the arrangement of electrons in atomic orbitals, and it can be quite complex, especially for atoms with many electrons. The respondents struggled with the intricacies of electron filling, including the rules governing the Pauli exclusion principle and Hund's rule. Electron configuration relies on abstract concepts, such as quantum numbers and atomic orbitals, which are not directly observable. This was evidenced in the majority of students' inability to provide a scientific response to question item 35, which expected students to explain the meaning of $5d^6$. Visualising the distribution of electrons in energy levels and sublevels were challenging for the students. These abstract concepts lead to a lack of understanding if not presented in a clear and relatable manner. Again, the absence of effective visual aids and teaching resources hindered the students' ability to understand electron configuration when taught in a regular classroom by their teacher through the traditional method. Visualizing electron distribution in atomic orbitals, as observed in question items 34, 38, and 39, was crucial for comprehension. Without access to clear and engaging visual materials, the students struggle to form mental models of these concepts.

The findings aligned with the initial problem statement, highlighting the inadequacies in the students' understanding of electron configuration and its related concepts. The study resonates with existing literature on the challenges students face in understanding the concept of electron configuration. The issues encountered by students in visualizing atomic orbitals, which is a fundamental aspect of electron configuration, were pointed out by Osei-Owusu's research conducted in 2007. This aligns with the current study's findings of students struggling with concepts like Pauli's exclusion principle and Hund's rule. Additionally, the study's findings corroborate the work of Hanson et al. (2012) as well as Dorris and Rau (2022), which emphasized the lack of background knowledge in electron configuration among undergraduate chemistry students. This research reaffirms the broader issues in understanding atomic and molecular orbitals, as indicated in previous studies.

### 4.2.2 Effect of flipped classroom approach on students' performance in electron configuration

The findings in this section highlight the significant effect of the flipped classroom learning approach on students' performance in electron configuration. The substantial increase in mean scores from the pretest to the post-test underscores the efficacy of this teaching methodology. The large eta squared value ($\eta^2 = 0.78$) indicates that a substantial proportion of the variance in student performance could be attributed to the flipped classroom learning approach. In practical terms, this suggests that the intervention led to a remarkable improvement in students' understanding, performance, and application of electron configuration concepts.

These findings are consistent with the broader literature on the effectiveness of the flipped classroom learning approach. This approach places emphasis on active learning, self-directed study, and the use of digital resources, as has been shown in previous studies to enhance student comprehension and performance. Soleymani et al. (2021) explored the impact of online resources and self-assessment in engineering education and found that students engaged in self-directed learning, a key component of the flipped classroom learning approach, performed significantly better. Pierce and Fox (2012) investigated the use of vodcasts and active learning exercises in a flipped classroom model, revealing that students who engaged with these resources demonstrated improved performance and understanding of complex topics. Talbert (2017) discussed the concept of "inverted learning" within a flipped classroom, emphasizing the benefits of shifting lecture content to online resources and allowing more in-class time for active learning. Moreover, research by Deslauriers et al. (2011) underscored the superiority of interactive-engagement methods over traditional teaching, highlighting the importance of student engagement in the learning process. Jensen et al. (2015) suggested that the improvements observed in flipped classrooms might be attributed to the incorporation of active learning, reinforcing the idea that student engagement is pivotal in enhancing performance. By providing students with pre-lessons electronically and allowing them to engage with the content at their own pace before attending class, the flipped classroom approach promotes a deeper understanding of complex topics like electron configuration.

The choice of the flipped classroom learning approach as an intervention strategy is supported by the work of Shater et al. (2023), which emphasized how this method can overcome resource constraints in high schools by utilizing online resources and videos to enhance learning. This current study also aligns with the research of Abeysekera and Dawson (2015), emphasizing the effectiveness of the flipped classroom learning approach in promoting self-directed learning, critical thinking, and problem-solving skills, which are crucial for understanding abstract topics like electron configuration. Furthermore, the findings support the practical application of the flipped classroom approach in addressing the specific challenge of students' inadequate understanding of electron configuration. This approach, by leveraging online resources, can help bridge resource constraints in schools and improve access to quality instructional materials, even in regions with limited physical resources like textbooks and laboratory equipment.

### 4.2.3 Effect of flipped classroom approach on students' retention of electron configuration

This current study found that the flipped classroom learning approach had a significant effect on students' retention of electron configuration concepts. The magnitude of the effect was large. This finding corroborates the findings of previous studies contained in existing literature that further support the implications of the findings regarding the impact of the flipped classroom approach on long-term retention of complex scientific concepts. Tofade et al. (2013) underscored the role of questions as a teaching tool in promoting active learning and retention, aligning with the notion that the flipped classroom approach, which encourages active engagement and questioning, can significantly enhance the retention of knowledge. Jin and Bridges (2016) explored the use of educational technologies in problem-based learning, highlighting the potential of technology-enhanced active learning, which improves long-term retention. Similarly, Smith et al. (2011) emphasised the impact of peer discussion and interactive, collaborative learning on not only enhancing initial understanding but also contributing to long-term retention. Additionally, Strayhorn (2018) underscores the significance of students' sense of belonging and engagement in educational success, which the flipped classroom, by fostering active learning and participation, can enhance, thereby improving long-term retention. Furthermore, Mazur (2009) discussed the limitations of traditional lectures and the benefits of interactive, student-centred learning, supporting the idea that active learning methods, such as those employed in the flipped classroom, are more effective in promoting deep understanding and long-term retention.

### 4.2.4 Students' perception of flipped classroom learning approach towards electron configuration

The results of this study highlighted a number of benefits of the flipped classroom learning approach, such as the positive response from students, the flexibility it provides for self-paced learning, and the way it fosters collaborative learning. The study's findings aligned with current educational literature that emphasizes the significance of technology integration in fostering student engagement and learning outcomes within the context of flipped learning (Means et al., 2013; Marougkas et al., 2023). The positive perception of the flipped classroom's effect on independence and self-directed learning resonated with contemporary theories advocating for student-centred approaches (Garner & Shank, 2023; Deci et al., 2017). This study emphasizes the advantages of the flipped classroom approach, such as confidence and improved learning outcomes through small group activities. This concurs with prior studies illustrating the merits of collaborative learning in enhancing students' understanding, critical thinking abilities, and problem-solving skills (Boateng et al., 2022; Cilliers & Pylman, 2022). Moreover, the reported benefits of increased practice and application were also aligned with recent research on the importance of active learning strategies for knowledge retention and transfer (Winn et al., 2019; Freeman et al., 2014). The students' positive perception of teacher support is consistent with the current discourse on the critical role of instructor guidance in online and technology-enhanced learning environments (Bates, 2015; Tsui et al., 2023).

Furthermore, this study's findings indicated the efficient utilization of in-class time for teacher-student interactions. The educators can thus provide prompt feedback and support, enabling students to better understand the material. This approach, according to Cevikbas and Kaiser (2020), better addresses students' questions and tailors' instruction to individual or small group needs, contributing to just-in-time instruction and personalized assistance. This study's conclusions about the interactive and collaborative learning environment are consistent with recent research (Qureshi et al., 2023). This emphasizes the importance of social constructivism and collaborative learning in digital education contexts. Also, the various perspectives about comfort and support highlight the continuous debate in the educational literature regarding the significance of accommodating a range of learning requirements and personal needs (Vilchez et al., 2021; Singh et al., 2022).

The finding showed that students strongly agreed that the flipped classroom learning approach significantly improved their academic achievement in electron configuration and that it was an effective way to learn the subject. The consistency in higher mean scores across these items highlighted a robust and consistent perception among students that the flipped classroom learning approach positively influenced their academic performance in electron configuration. These findings strengthen existing literature on the efficacy of flipped learning in enhancing students' learning outcomes (Means et al., 2013; Freeman et al., 2014). It also supports the idea that the flipped classroom learning approach serves as an effective pedagogical strategy for improving academic achievement in complex topics such as electron configuration.

Nonetheless, despite the overwhelming positive outcomes, it is essential to acknowledge that the students did encounter challenges in flipped classroom learning. These challenges, primarily of a systematic and technical nature, were associated with school management systems and ICT equipment, resulting in a negative impact on their learning experience to some extent. This development is similar to challenges reported in previous studies, that inadequate ICT skills and competence would lead to students experiencing technical difficulties when using such equipment (Yilmaz & Malone 2020). Overall, the study's implications aligned with and contributed to the evolving landscape of educational research and practice, reflecting the dynamic interplay between pedagogy, technology, and individual learner characteristics.

# CHAPTER FIVE

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 5.0 Overview

This chapter mainly focuses on summary of key findings, drawing conclusions to the study from the findings and making commendations. Other aspects include suggestions for further studies.

## 5.1 Summary of Key Findings

The summary of the major findings was indicated as follows:

a. The majority of the students in the intact class lacked substantial conceptual understanding of electron configuration, although their teacher has taught them the topic in regular class.

b. Students lack fundamental knowledge in understanding concepts such as Pauli's exclusion principle, Hund's rule of maximum multiplicity, and the number of unpaired electrons in various elements, which are key components of electron configuration.

c. The flipped classroom approach was highly effective in positively influencing students' academic performance in electron configuration, as reflected by a significant improvement in mean scores from the pretest to the post-test.

d. The study found that the flipped classroom learning approach engages students in self-directed learning, critical thinking and problem-solving strategies through collaboration that significantly improved their performance in electron configuration.

e. The flipped classroom learning approach does have a statistically significant effect on students' retention of electron configuration concepts. The magnitude of the effect in retaining electron configuration concepts among the students was large.

f. Students' overall perception about the flipped classroom approach in learning electron configuration was highly satisfactory.

## 5.2 Conclusions

The flipped classroom learning intervention as one of the convenience students centred approach to learning was introduced to improve students' performance in electron configuration. Students hardly understand the concepts of electron configuration when taught by their teacher through as indicated by the findings of this study. The findings indicated a deficiency in students' comprehension, particularly in understanding fundamental concepts related to atomic orbitals.

The statistical significant improvement of students' academic performance in electron configuration coupled with a noteworthy effect size, suggests that flipping the classroom positively influences students' academic performance. Flipped classroom learning approach is a fun, efficient and fulfilling way to teach and learn, as evidenced by the findings of this study. This learning approach contributes not only to immediate understanding, but to ensure retention of crucial chemical concepts relating to electron configuration over time.

The students' favourable perception of the flipped classroom learning approach towards electron configuration revealed a high level of comfort with technology, increased independence, engagement, and a more effective and enjoyable learning experience. The positive effect on conceptual understanding, academic performance, and retention, coupled with favorable students' perception, suggests that the flipped classroom is a promising avenue for transforming traditional teaching methods.

### 5.3 Recommendations

The following recommendations are put forward based on the findings of the study.

1. **Educational Practice:** The study recommends the integration of flipped classroom methodologies in chemistry education at Mankessim Senior High Technical School (MSHTS) to enhance students' conceptual understanding, performance, and retention of challenging topics like electron configuration
2. **Professional Development:** Teachers in the study school should receive training and support from resource personnels engaged by the school management to effectively implement flipped learning strategies, ensuring a seamless transition from traditional teaching methods to more student-centred approaches. The Professional Learning Community (PLC) platform periods can be used for such training of teachers.
3. **Resource Allocation:** School management in the study school may need to invest in technology resources to facilitate the implementation of flipped classroom learning approach as it has the tendency to promote students' interest in learning chemistry.
4. **Curricular Design:** The positive student perceptions suggest the need for curricular adjustments by teachers in MSHTS to incorporate flipped learning elements, fostering a more engaging and interactive learning environment among students in the school.

### 5.4 Suggestions for Further Studies

Based on the findings and implications of the current research, here are some suggestions for future research endeavours:

1. **Long-Term Impact Assessment:** a longitudinal study should be conducted to investigate the sustained impact of the flipped classroom approach on students'

academic performance and retention. This could involve tracking participants over an extended period, potentially throughout their academic journey, to assess the long-term impact on their understanding of electron configuration and related topics.

2. **Comparative Studies:** comparative studies on the effectiveness of the flipped classroom approach in contrast to other pedagogical methods can be explored. This could involve comparing outcomes with inquiry-based learning, or other active learning strategies to identify the strengths and weaknesses of each approach.
3. **Discipline-Specific Investigations:** The research can be extended to other disciplines within science education to assess the applicability and effectiveness of the flipped classroom approach in different areas of chemistry or other scientific subjects. Each discipline may have unique challenges and opportunities that could be explored through tailored flipped classroom interventions.
4. **Teacher Training and Professional Development:** further studies can Investigate the impact of teacher training and professional development programs focused on flipped learning methodologies. Understanding how educators' preparation and ongoing support contribute to the success of flipped classroom initiatives is crucial for widespread implementation.
5. **Technology Integration:** Explore the role of specific technologies in the flipped classroom model. Investigate how different multimedia resources, interactive simulations, or virtual laboratories contribute to students' conceptual understanding and engagement in the learning process.

6. **Student Demographics and Learning Styles:** Consider how student demographics and learning styles influence the effectiveness of the flipped classroom approach. Analyze whether certain groups of students (e.g., diverse socioeconomic backgrounds, different learning preferences) benefit more or less from this instructional method.
7. **Interdisciplinary Investigations:** Collaborate with researchers from other disciplines, such as education psychology or technology integration, to gain a holistic understanding of the cognitive and affective aspects of flipped learning. Interdisciplinary research can provide comprehensive insights into the dynamics of this pedagogical approach.

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# APPENDIX

## APPENDIX A: PRE-TEST

**UNIVERSITY OF EDUCATION WINNEBA**

**FACULTY OF SCIENCE EDUCATION**

**DEPARTMENT OF CHEMISTRY EDUCATION**

**PRE-TEST**

Purpose: This pre-test seeks to find out your conceptual understanding of electron configuration before flipped classroom learning (FCA) approach. This exercise is being conducted for research purposes only because of this, marks obtained on the test will be treated confidentially. Thank you for your cooperation.

BIO-DATA OF THE RESPONDENT

GENDER: Male ☐ Female ☐ Age 15 - 17 ☐ 18 - 20 ☐

Instruction

*This test consists of two sections; A & B. For section A, circle the correct option to each item, for B provide your candid answers in the spaces provided. Answer all the questions on this paper for 45 marks. Duration: 50 minutes.*

**[30 marks]**

**SECTION A**

**MULTIPLE CHOICE QUESTIONS**

*Each correct answer attracts 1 mark*

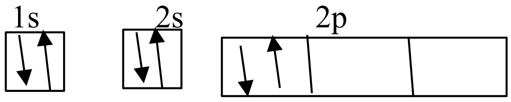
1. The total number of electrons that can occupy the principal energy level is…….

   A. 2

   B. 8

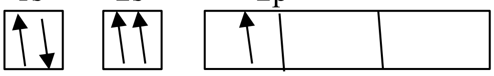
   C. n

   D. $2n^2$

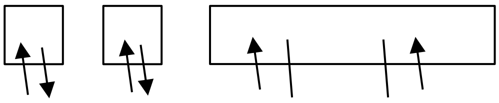
2. For an electron with angular quantum number $l$ = 2, the magnetic quantum number can have.........
   A. An infinite number of values
   B. Only one value
   C. One of two possible values
   D. One of five possible values
3. An electron cannot have the quantum numbers n = ______ , $l$ = ______ m$l$ = ______
   A. 2, 0, 0
   B. 2, 1, 1
   C. 3, 1, - 1
   D. 1, 1, 1
4. Which one of the following is an impossible subshell notation?
   A. 4f
   B. 2d
   C. 3s
   D. 2p
5. A 3p can have a possible magnetic quantum number of values of.........
   A. 3 and 6
   B. -2, -1, 0 and 1
   C. 3, 2 and 1
   D. -1, 0 and 1
6. Which electronic configuration represents a violation of Pauli's exclusion principle?
   A. 

B. 1s 2s 2p

C. 1s 2s 2p



D. 1s 2s 2p



7. What is the correct electronic configuration for $Mg^{2+}$?

A. $1s^2\ 2s^2\ 2p^6$

B. $1s^2\ 2s^2\ 2p^6\ 3s^2$

C. $1s^2\ 2s^2\ 2p^5\ 3s^1$

D. $1s^2\ 2s^2\ 2p^4\ 3s^2$

8. A certain transitional metal has an electron configuration such that its 4s orbital only has one electron. What would be a valid conclusion about this element?

A. This is an invalid electronic configuration because 4s orbital always contain two electrons in transition metals

B. The identity of the element is Manganese and it contain an empty 3d orbital

C. The identity of the element is Chromium and it contain one electron in each 3d orbital

D. The identity of the element is Manganese and it contains one electron in each 3d orbital

9. An atom with the electron configuration of $ls^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$ has an incomplete…….

A. 2p sublevel

B. second principal energy level

C. third principal energy level

D. 4s sublevel

10. Pauli's exclusion principle is related to.........

A. Quantum numbers of electrons

B. Filling degenerate orbitals

C. Filling the orbitals with lower energy first

D. Quantity of electrons in the valence shell

11. Bohr's model of the atom proposed the existence of........

A. The nucleus

B. Nucleons

C. Electron shells

D. Neutrons

12. Which of the following species is represented by the electron configuration $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^5$ $4s^1$?

A. Fe

B. Cr

C. Mn

D. Mo

13. How many orbitals are contained in an atom with atomic number 13?

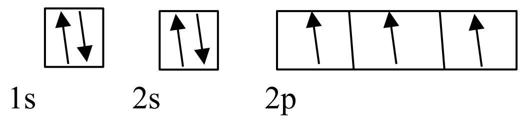
A. 7

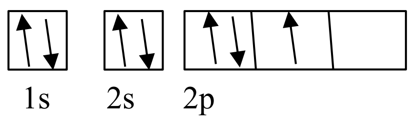
B. 6

C. 5

D. 13

14. The electron configuration of Nitrogen is represented as




and not

This is in accordance with…………

A. Quantum theory

B. Pauli's Exclusion principle

C. Hund's Rule of Maximum multiplicity

D. Aufbau principle

15. Which of the following statements is **true**?

A. An electron in an n = 1 shell has lower energy than an electron in an n =2 shell

B. All subshells contain same number of electrons

C. The number of subshells within a shell is equal to the orbital number

D. All subshells have an identical shape and size

16. Which electron configuration represents an atom in an excited state?

A. $1s^22s^22p^63p^1$

B. $1s^22s^22p^63s^23p^1$

C. $1s^22s^22p^63s^23p^2$

D. $1s^22s^22p^63s^2$

17. Which sublevel electron configuration correctly represents a completely filled third principal energy level?

A. $3s^23p^63d^8$

B. $3s^23p^23d^{10}$

C. $3s^23p^63d^{10}$

D. $3s^2 3p^6 3d^5$

18. All of the elements in Period 3 have a total of 2 electrons in the……….

A. 2*s* sublevel

B. 3*s* sublevel

C. 2*p* sublevel

D. 3*p* sublevel

19. Which atom in the ground state contains a partially filled 3p orbital?

A. Argon

B. Calcium

C. Potassium

D. Aluminum

20. Which atom in the ground state has three unpaired electrons in its outermost principal energy level?

A. Li

B. B

C. N

D. Ne

21. In the ground state, the atoms of elements in Period 2 all have the same number of………

A. Protons

B. Neutrons

C. 1s electrons

D. Oxidation state

22. What is the total number of valence electrons in an atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?

A. 6

B. 3

C. 2

D. 5

23. Which element has a completely filled third principal energy level?

A. Ar

B. Ne

C. Fe

D. Zn

24. A maximum of 6 electrons can occupy………

A. an *s* orbital

B. an *s* sublevel

C. a *p* orbital

D. a *p* sublevel

25. Which of the following represents the electron configuration of the outermost principal energy level of a Group 15 element in the ground state?

A. $s^2p^3$

B. $s^2p^5$

C. $s^1p^3$

D. $s^1p^5$

26. In the ground state, which element's atoms have five completely filled orbitals?

A. Li

B. B

C. C

D. Ne

27. An atom with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$ has an incomplete……

    A. 2*p* sublevel

    B. second principal energy level

    C. third principal energy level

    D. *4s* sublevel

28. Which electron transition represents the release of energy?

    A. 1*s* to 3*p*

    B. 2*s* to 2*p*

    C. 3*p* to 1*s*

    D. 2*p* to 3*s*

29. How does the ground state electron configuration of the hydrogen atom differ from that of a ground state helium atom?

    A. Hydrogen has one electron in a higher energy level.

    B. Hydrogen has two electrons in a lower energy level

    C. Hydrogen contains a half-filled orbital

    D. Hydrogen contains a completely filled orbital

30. Which of the following represents the electron configuration of an isotope of oxygen in the ground state?

    A. $1s^2 2s^2 2p^1$

    B. $1s^2 2s^2 2p^2$

    C. $1s^2 2s^2 2p^3$

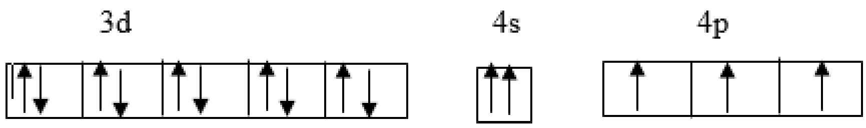
    D. $1s^2 2s^2 2p^4$

**[15 marks]**

## SECTION B

***Answer all the questions in this section. All answers should be written in the spaces provided.***

31. Explain why the ground state electron configuration stated below is incorrect.




[ 1 mark]

32. Indicate the reason why the ground state electron configuration below is incorrect.


[1 mark]

33. Use the electron configuration of $_{16}$**S** to identify its period and group number.

[2 marks]

34. State the number of unpaired electrons in the electron configuration of $_{29}$**Cu.**

[1 mark]

35. Explain the meaning of ***5d***$^{6}$ as applied in electron configuration.

[3 marks]

36. Write the electron configuration of $_{9}\mathbf{F}^{-}$

[1 mark]

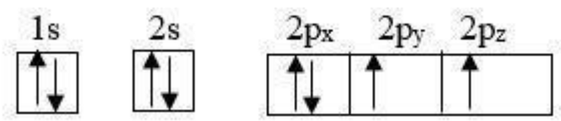
37. Write the electron configuration of ***Iron*** (Z=26) after donating two electrons.

[2 marks]

38. Give the detail electron configuration of $_{24}\mathbf{Cr}$.

[1 mark]

39. Explain the significance of the ***arrows*** and letters ***x, y and z*** in the given electron configuration below.



[2 marks]

40. How many electrons can be accommodated in a set of ***f*** orbitals.

-----------------------------------------------------------------------

[1 mark]

## APPENDIX B: POST TEST

**UNIVERSITY OF EDUCATION WINNEBA**

**FACULTY OF SCIENCE EDUCATION**

**DEPARTMENT OF CHEMISTRY EDUCATION**

**POST-TEST**

Purpose: This post-test seeks to find out your conceptual understanding of electron configuration after the flipped classroom learning (FCL) approach. This exercise is being conducted for research purposes only because of this, marks obtained on the test will be treated confidentially. Thank you for your cooperation.

BIO-DATA OF THE RESPONDENT

GENDER: Male ☐ Female ☐ Age 15 - 17 ☐ 18 - 20 ☐

**Instruction**

*This test consists of two sections; A & B. For section A, circle the correct option to each item, for B provide your candid answers in the spaces provided. Answer all the questions on this paper for 45 marks. Duration: 50 minutes.*

**SECTION A**

**[30 marks]**

**MULTIPLE CHOICE QUESTIONS**

*Each correct answer attracts 1 mark*

1. A certain transitional metal has an electron configuration such that its 4s orbital only has one electron. What would be a valid conclusion about this element?
   A. This is an invalid electronic configuration because *4s* orbital always contain two electrons in transitional metals
   B. The identity of the element is Manganese and it contain an empty *3d* orbital

C. The identity of the element is Chromium and it contain one electron in each *3d* orbital

D. The identity of the element is Manganese and it contains one electron in each *3d* orbital

2. An atom with the electron configuration of $ls^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$ has an incomplete………

A. 2p sublevel

B. second principal energy level

C. third principal energy level

D. 4s sublevel

3. Aufbau's principle is related to……….

A. Quantum numbers of electrons

B. Filling degenerate orbitals

C. Filling the orbitals with lower energy first

D. Quantity of electrons in the valence shell

4. Which of the following species is represented by the electron configuration $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^6$ $4s^2$?

A. Fe

B. Cr

C. Mn

D. Mo

5. How many orbitals are contained in an atom with atomic number 13………

A. 7

B. 6

C. 5

D. 13

6. Which of the following statements is **true**?

A. An electron in an n = 1 shell has lower energy than an electron in an n =2 shell

B. All subshells contain same number of electrons

C. The number of subshells within a shell is equal to the orbital number

D. All subshells have an identical shape and size

7. Which sublevel electron configuration correctly represents a completely filled third principal energy level?

A. $3s^2 3p^6 3d^8$

B. $3s^2 3p^2 3d^{10}$

C. $3s^2 3p^6 3d^{10}$

D. $3s^2 3p^6 3d^5$

8. All of the elements in *Period 3* have a total of 2 electrons in the……….

A. 2*s* sublevel

B. 3*s* sublevel

C. 2*p* sublevel

D. 3*p* sublevel

9. Which atom in the ground state contains a partially filled *3p* orbital?

A. Argon

B. Calcium

C. Potassium

D. Aluminum

10. Which atom in the ground state has two unpaired electrons in its outermost principal energy level?

A. Li

B. O

C. N

D. Ne

11. In the ground state, the atoms of elements in Period 2 all have the same number of………

A. Protons

B. Neutrons

C. 1s electrons

D. Oxidation state

12. What is the total number of valence electrons in an atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?

A. 6

B. 3

C. 2

D. 5

13. Which element has a completely filled third principal energy level?

A. Ar

B. Ne

C. Fe

D. Zn

14. A maximum of 10 electrons can occupy……….

A. a *d* sublevel

B. an *s* sublevel

C. a *d* orbital

D. a *p* sublevel

15. Which of the following represents the electron configuration of the outermost principal energy level of a Group 15 element in the ground state?

A. $s^2p^3$

B. $s^2p^5$

C. $s^1p^3$

D. $s^1p^5$

16. In the ground state, which element's atoms have five completely filled orbitals?

A. Li

B. B

C. C

D. Ar

17. An atom with the electron configuration of $ls^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ has an incomplete……

A. 2*p* sublevel

B. second principal energy level

C. third principal energy level

D. 4*s* sublevel

18. Which electron transition represents the release of energy?

A. 4*p* to 3*s*

B. 2*s* to 2*p*

C. 3*p* to 3*s*

D. 2*p* to 3*s*

19. Which of the following represents the electron configuration of an isotope of Sulphur in the ground state?

A. $1s^2 2s^2 2p^6 3s^2 3p^4$

B. $1s^2 2s^2 2p^2 3s^2 3p^6$

C. $1s^2 2s^2 2p^6 3s^2 3p^3$

D. $1s^2 2s^2 2p^4 3s^2 3p^4$

20. How many orbitals are in d sub shell?

A. 7

B. 5

C. 3

D. 1

21. Which of the following ions has the same electron configuration as argon?

A. $Na^+$

B. $Mg^{2+}$

C. $K^+$

D. $Ca^{2+}$

22. Which of the following statements is true regarding the electron configuration of an atom in its ground state?

A. The electron configuration of an atom in its ground state is always the same as its electron configuration in an excited state

B. The electron configuration of an atom in its ground state is the arrangement of electrons in the lowest energy levels and sublevels

C. The electron configuration of an atom in its ground state is the arrangement of electrons in the highest energy levels and sublevels

D. The electron configuration of an atom in its ground state is determined by the number of neutrons in the atom.

23. For an electron with angular quantum number l = 0, the magnetic quantum number can have……….

A. An infinite number of values

B. Only one value

C. One of two possible values

D. One of five possible values

24. Which of the following is the correct electron configuration for a carbon atom in its excited state?

A. $1s^2 2s^2 2p^2$

B. $1s^2 2s^1 2p^3$

C. $1s^2 2s^2 2p^3$

D. $1s^2 2s^2 2p^4$

25. A 5p can have a possible magnetic quantum number of values of……….

A. 5 and 6

B. -2, -1, 0 and 1

C. 3, 2 and 1

D. -1, 0 and 1

26. The valence electrons in $_5B$ are in the………

A. 1s orbital

B. $2p_x$ orbital

C. 2s orbital

D. 2p orbital

27. What is the electron configuration of ***Iron*** ion with a charge of +2?

A. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$

B. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$

C. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

D. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7$

28. Which one of the following is an impossible subshell notation?

A. 4f

B. 2s

C. 2d

D. 3p

29. Which of the following elements has a completely filled *3p* subshell in its ground state?

A. N

B. O

C. F

D. Ne

30. Which of the following subshells has the highest energy?

A. 3s

B. 5f

C. 4d

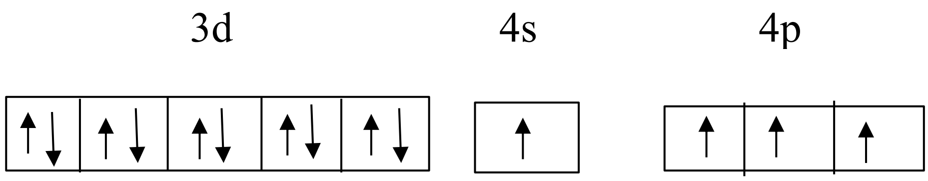
D. 2p

**SECTION B**

**[15 marks]**

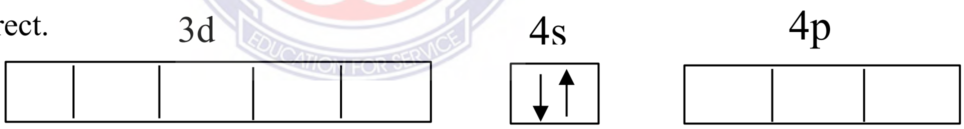
***Answer all the questions in this section. All answers should be written in the spaces provided.***

31. State with reason if the ground state electron configuration stated below is correct or incorrect.




[1 mark]

32. Indicate with reason if the ground state electron configuration below is correct or incorrect.




[1 mark]

33. Use the s, p, d and f electron configuration notation of $_{15}$**P** to identify its period and group number.

-----------------------------------------------------------------------

[2 marks]

34.Write the electron configuration of **oxide ion** and use it to determine the number of unpaired electrons.

-----------------------------------------------------------------------

[2 mark]

35. Explain the meaning of ***4f*** $^{7}$ as applied in electron configuration.

-----------------------------------------------------------------------

-----------------------------------------------------------------------

[3 marks]

36. Write the electron configuration of $_{8}O^{--2}$

-----------------------------------------------------------------------

[1 mark]

37. Write the electron configuration of ***copper*** (Z=29) after donating two electrons.

-----------------------------------------------------------------------

[1 mark]

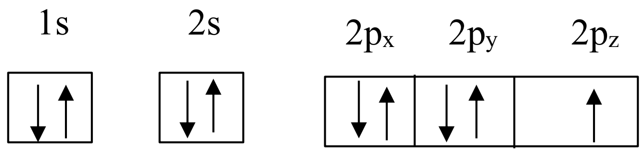
38. State the reason(s) why the correct electron configuration of $_{24}$**Cr** written as $_{18}$***[Ar]4s***$^{1}$***3d***$^{5}$ does not violate Aufbau principle.

-----------------------------------------------------------------------

-----------------------------------------------------------------------

[1 mark]

39. What does the ***arrows*** and letters ***x, y and z*** represent in the given ground state electron configuration of $_{9}F$




[2 marks]

40. How many electrons can be accommodated in a $p_x$ orbital?

[1 mark]

## APPENDIX C: DELAYED POST-TEST

UNIVERSITY OF EDUCATION WINNEBA

FACULTY OF SCIENCE EDUCATION

DEPARTMENT OF CHEMISTRY EDUCATION

DELAYED POST-TEST

Purpose: This delayed post-test seeks to find out your conceptual understanding of electron configuration after the flipped classroom learning (FCL) approach. This exercise is being conducted for research purposes only because of this, marks obtained on the test will be treated confidentially. Thank you for your cooperation.

BIO-DATA OF THE RESPONDENT

GENDER: Male ☐ Female ☐ Age 15 - 17☐ 18 - 20☐

Instruction

*This test consists of two sections; A & B. For section A, circle the correct option to each item, for B provide your candid answers in the spaces provided. Answer all the questions on this paper for 45 marks. Duration: 50 minutes.*

### SECTION A [30 Marks]

### MULTIPLE CHOICE QUESTIONS

Each correct answer attracts 1 mark

1. Which of the following statements is **true**?
   A. An electron in an n = 1 shell has lower energy than an electron in an n =2 shell
   B. All subshells contain same number of electrons
   C. The number of subshells within a shell is equal to the orbital number
   D. All subshells have an identical shape and size

2. An atom with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ has an incomplete……

   A. 2p sublevel
   B. second principal energy level
   C. third principal energy level
   D. 4s sublevel

3. For an electron with angular quantum number $l$ = 0, the magnetic quantum number can have………

   A. An infinite number of values
   B. Only one value
   C. One of two possible values
   D. One of five possible values

4. Which of the following elements has a completely filled *3p* subshell in its ground state?

   A. N  B. O  C. F  D. Ne

5. Which of the following is the correct electron configuration for a carbon atom in its excited state?

   A. $1s^2\ 2s^2\ 2p^2$  B. $1s^2\ 2s^1\ 2p^3$  C. $1s^2\ 2s^2\ 2p^3$  D. $1s^2\ 2s^2\ 2p^4$

6. Which of the following statements is true regarding the electron configuration of an atom in its ground state?

   A. The electron configuration of an atom in its ground state is always the same as its electron configuration in an excited state
   B. The electron configuration of an atom in its ground state is the arrangement of electrons in the lowest energy levels and sublevels
   C. The electron configuration of an atom in its ground state is the arrangement of electrons in the highest energy levels and sublevels

D. The electron configuration of an atom in its ground state is determined by the number of neutrons in the atom.

7. Which of the following subshells has the highest energy?

A. 3s B. 5f C. 4d D. 2p

8. Which one of the following is an impossible subshell notation?

A. 4f B. 2s C. 2d D. 3p

9. A maximum of 10 electrons can occupy.

A. a d sublevel B. an s sublevel C. a d orbital D. a p sublevel

10. Which electron transition represents the release of energy?

A. 4p to 3s B. 2s to 2p C. 2p to 3s D. 2p to 3s

11. What is the total number of valence electrons in an atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?

A. 6 B. 3 C. 2 D. 5

12. How many orbitals are contained in an atom with atomic number 13……….

A. 7 B. 6 C. 5 D. 13

13. Which of the following represents the electron configuration of an isotope of Sulphur in the ground state?

A. $1s^2 2s^2 2p^6 3s^2 3p^4$

C. $1s^2 2s^2 2p^6 3s^2 3p^3$

B. $1s^2 2s^2 2p^2 3s^2 3p^6$

D. $1s^2 2s^2 2p^4 3s^2 3p^4$

14. Which atom in the ground state contains a partially filled 3p orbital?

A. Argon

C. Potassium

B. Calcium

D. Aluminum

15. In the ground state, which element's atoms have five completely filled orbitals?

A. Li B. B C. C D. Ar

16. Which of the following represents the electron configuration of the outermost principal energy level of a group 5 element in the ground state?

    *A.* $s^2p^3$
    *B.* $s^2p^5$
    *C.* $s^1p^3$
    *D.* $s^1p^5$

17. Which element has a completely filled third principal energy level?

    A. Ar B. Ne C. Fe D. Zn

18. For an electron with angular momentum quantum number l = 0, the magnetic quantum number can have…………

    A. An infinite number of values
    B. Only one value
    C. One of two possible values
    D. One of five possible values

19. Which of the following species is represented by the electron configuration $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^6$ $4s^2$?

    A. Fe B. Cr C. Mn D. Mo

20. Which of the following ions has the same electron configuration as argon?

    A. $Na^+$ B. $Mg^{2+}$ C. $K^{2+}$ D. $Ca^{2+}$

21. A certain transitional metal has an electron configuration such that its 4s orbital only has one electron. What would be a valid conclusion about this element?

    A. This is an invalid electronic configuration because 4s orbital always contain two electrons in transitional metals
    B. The identity of the element is Manganese and it contain an empty 3d orbital
    C. The identity of the element is Chromium and it contain one electron in each 3d orbital
    D. The identity of the element is Manganese and it contains one electron in each 3d orbital

22. Which sublevel electron configuration correctly represents a completely filled third principal energy level?

A. $3s^23p^63d^8$ B. $3s^23p^23d^{10}$ C. $3s^23p^63d^{10}$ D. $3s^23p^63d^5$

23. All of the elements in Period 3 have a total of 2 electrons in the……….

A. 2s sublevel B. 3s sublevel C. 2p sublevel D. 3p sublevel

24. Which atom in the ground state contains a partially filled 3p orbital?

A. Argon B. Calcium C. Potassium D. Aluminum

25. The valence electrons in $_5B$ are in the………

A. *1s* orbital B. $2p_x$ orbital C. *2s* orbital D.*2p* orbital

26. What is the electron configuration of Iron ion with a charge of +2?

A. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$ C. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

B. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$ D. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7$

27. Which one of the following is an impossible subshell notation?

A. 4f B. 2s C. 2d D. 3p

28. In the ground state, the atoms of elements in Period 2 all have the same number of………

A. Protons B. Neutrons C. 1s electrons D. Oxidation state

29. Which atom in the ground state has two unpaired electrons in its outermost principal energy level?

A. Li B. O C. N D. Ne

30. Aufbau's principle is related to

A. Quantum numbers of electrons C. Filling the orbitals with lower energy first

B. Filling degenerate orbitals

D. Quantity of electrons in the valence shell

**SECTION B [15 Marks]**

***Answer all the questions in this section. All answers should be written in the spaces provided.***

31. How many electrons can be accommodated in a $\boldsymbol{p_x}$ orbital? [1 mark]

.....................................................................................................

32. Write the electron configuration of copper (Z=29) after donating two electrons [1 mark]

.....................................................................................................

33. Use the *s*, *p*, *d* and *f* electron configuration notation of $_{20}Ca$ to identify its period and group number. [2 marks]

.....................................................................................................

.....................................................................................................

34. Write the electron configuration of oxide ion and use it to determine the number of unpaired electrons. [2 marks]

.....................................................................................................

35. What does the arrows and letters *x, y* and z represent in the given ground state electron configuration of $_9F$?

[2 marks]

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

36. Write the electron configuration of ${}_{16}S^{-2}$. [1 mark]

…………………………………………………………………………………………

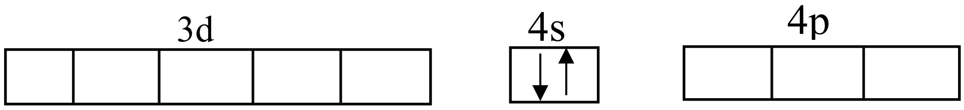
37. State with reason if the ground state electron configuration stated below is correct or incorrect.


…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

38. Indicate with reason if the ground state electron configuration below is correct or incorrect [2 marks]




…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

39. Explain the meaning of $\mathbf{3d^{10}}$ as applied in electron configuration [3 marks]

………………………………………………………………………………………………

……………………………………………………………………………………………

40. State the reason(s) why the correct electron configuration of $_{24}\mathbf{Cr}$ written as $_{18}[Ar]4s^{1}3d^{5}$ do not violate Aufbau principle [1 mark]

……………………………………………………………………………………………

# APPENDIX D

## MARKING SCHEMES FOR ELECTRON CONFIGURATION ACHIEVEMENT TEST, PRETEST, POST-TEST.

## MARKING SCHEME FOR PRE-TEST QUESTIONS

### SECTION A [30 MARKS]

MULTIPLE CHOICE QUESTIONS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. D | 2. D | 3. D | 4. B | 5. D | 6. C | 7. A | 8. C | 9. C | 10.D |
| 11. C | 12.B | 13 A | 14C | 15.A | 16. A | 17. C | 18 A | 19.D | 20C |
| 21. C | 22.D | 23.D | 24.D | 25A | 26D | 27C | 28C | 29C | 30.D |

### SECTION B [15 MARKS]

31. 4s violate Pauli's exclusion principle 1 mark

32. 4p violates Hund's rule of maximum multiplicity 1 mark

33. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$,

Therefore, the period is 3 and the group number is 6 2 marks

34. From the E.C of Cu $_{18}$[Ar] $4s^1\ 3d^{10}$.

This implies the number of unpaired **electron** is one 1 mark

35. **5** means principal energy level/ principal quantum number

**d** means sublevel/ suborbital/ angular momentum quantum number

6 means number of electrons in the orbital or sublevel

3 * 1 mark 3 marks

36. Electron Configuration for ${}_{9}F$ -

$1s^2\ 2s^2\ 2p^6$ 1 mark

37. Electron Configuration of ${}_{26}Fe$ after donating 2 electrons

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^0\ 3d^5$ 2 marks

38. Electron Configuration for 24 Cr

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^5$ 1 mark

39. The significance of arrows and letters **x**, **y** and **z**

arrows indicate the spin of electrons

the letters represent the direction in space of the three *p*- orbitals

along x, y, z axes respectively

2 * 1 mark each 2 marks

40. 14 electrons 1 mark

## MARKING SCHEME FOR POST TEST QUESTIONS

## SECTION A [30 MARKS]

## MULTIPLE CHOICE QUESTIONS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1C | 2.C | 3.C | 4.A | 5.A | 6.A | 7.C | 8.A | 9.D | 10.B |
| 11.C | 12.D | 13.D | 14.C | 15.A | 16.D | 17.D | 18.C | 19.A | 20.B |
| 21.D | 22.B | 23.B | 24.B | 25.D | 26.B | 27.C | 28.C | 29.D | 30.B |

## SECTION B [15 MARKS]

31. Electron configuration is **correct** because of the consideration of the stability associated with **half – filled** and **fully – filled orbitals** 1 mark

32. **Aufbau's Rule** is obeyed, hence electron configuration is **correct** 1 mark

33. Identification of period and group for 15P

    1s2 2s2 2p6 3s2 3p3 hence period is 3 and group is 5 2 marks

34. EC for Oxide ion to determine the number of unpaired

    1s2 2s2 2p6 1 mark

    number of unpaired electrons = 0 1 mark

35. **4** means principal energy level ⁄ principal quantum number

    ***f*** means sublevel ⁄suborbital ⁄angular momentum quantum number

    **7** means number of electrons in the orbital or sublevel

    3 * 1 mark 3 marks

36. EC of $_8O^{-2}$

1s2 2s2 2p6 1 mark

37. EC of copper after donating two electrons

1s2 2s2 2p6 3s2 3p6 4s0 3d9 1 mark

38. In writing the electron configuration of atoms stability is always associated with half-filled and fully – filled orbitals.

1 mark

39. The significance of arrows and letters **x**, **y** and **z**

arrows indicate the spin of electrons

the letters represent the direction in space of the three *p*- orbitals along x, y, z axes respectively

2 * 1 mark each 2 marks

40. Only 2 electrons. 1 mark

## APPENDIX E

FLIPPED CLASSROOM ELECTRON CONFIGURATION PERCEPTION QUESTIONNAIRE

UNIVERSITY OF EDUCATION WINNEBA

FACULTY OF SCIENCE EDUCATION

DEPARTMENT OF CHEMISTRY EDUCATION

FLIPPED CLASSROOM LEARNING ELECTRON CONFIGURATION PERCEPTION SCALE (FCLECPS)

***Rate by ticking each item on the scale provided to indicate your agreement or disagreement***

**Part 1: Demographic Information**

1. What is your gender?

   [ ] Male [ ] Female

2. What is your age?

   [ ]Under 18 years old [ ]18-20 years old

**Part 2: Flipped Classroom Experience**

3. I was comfortable using technology (e.g., pre-recorded videos,) in the flipped classroom approach for learning electron configuration.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

4. The flipped classroom method provided me with enough time to prepare for class activities related to electron configuration.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

5. The flipped classroom method made it easier for me to ask questions and get clarifications about electron configuration.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

6. The flipped classroom method helped me to become more independent and self-directed in my learning of electron configuration.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

7. The flipped classroom method provided me with more opportunities to practice and apply electron configuration concepts.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

8. The flipped classroom method made it easier for me to keep up with the pace of the electron configuration course.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

9. The flipped classroom method allowed me to learn electron configuration at my own pace and in my own time.

   [ ] Strongly disagree

   [ ] Disagree

   [ ] Neither agree nor disagree

   [ ] Agree

   [ ] Strongly agree

10. The flipped classroom method provided me with a variety of resources to learn electron configuration (e.g., videos, readings).

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

11. The flipped classroom method increased my confidence in understanding electron configuration concepts and solving related problems.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

12. The flipped classroom method was more engaging than conventional classroom instruction for learning electron configuration.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

**Part 3: Teacher Support**

13. The teacher provided clear and concise instructions on how to use the flipped classroom approach for learning electron configuration.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

14. Instructor was able to provide classification on difficult concepts during the flipped classroom activity

[ ] strongly agree

[ ] agree

[ ] neither agree nor disagree

[ ] disagree

[ ] strongly disagree

15. The teacher provided prompt and useful feedback on my progress in learning electron configuration through the flipped classroom approach.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

16. Instructor was able to expand on pre-recorded lesson videos and pre-reading material during in-class face-to-face lesson

[ ] strongly agree

[ ] agree

[ ] neither agree nor disagree

[ ] disagree

[ ] strongly disagree

17. The teacher provided adequate resources and materials to support my learning of electron configuration through the flipped classroom approach.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

**Part 4: Learning Environment**

18. The flipped classroom approach provided a comfortable and supportive learning environment for me to learn electron configuration.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

19. The flipped classroom approach allowed me to collaborate and engage in discussions with my peers while learning electron configuration.

    [ ] Strongly disagree

    [ ] Disagree

    [ ] Neither agree nor disagree

    [ ] Agree

    [ ] Strongly agree

20. The flipped classroom approach allowed me to be more independent and take ownership of my learning of electron configuration.

    [ ] Strongly disagree

    [ ] Disagree

    [ ] Neither agree nor disagree

    [ ] Agree

    [ ] Strongly agree

21. The classroom arrangement (positioning of the chairs for group activity) was conductive for the flipped classroom activity.

    [ ] strongly agree

    [ ] agree

    [ ] neither agree nor disagree

    [ ] disagree

    [ ] strongly disagree

**Part 5: Academic Achievement in Electron Configuration**

22. The flipped classroom approach helped me develop better time management and study skills for learning electron configuration.

    [ ] Strongly disagree

    [ ] Disagree

    [ ] Neither agree nor disagree

    [ ] Agree

    [ ] Strongly agree

23. The flipped classroom approach was an effective way to learn electron configuration.

    [ ] Strongly disagree

    [ ] Disagree

    [ ] Neither agree nor disagree

    [ ] Agree

    [ ] Strongly agree

24. The flipped classroom approach improved my academic achievement in electron configuration.

    [ ] Strongly disagree

    [ ] Disagree

    [ ] Neither agree nor disagree

    [ ] Agree

    [ ] Strongly agree

**Part 6: Overall Assessment**

25. I would recommend the flipped classroom approach to other students for learning electron configuration.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

26. I found the flipped classroom approach for learning electron configuration to be a positive experience.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

27. I believe that the flipped classroom approach could be used in other subjects to enhance student learning and academic achievement.

[ ] Strongly disagree

[ ] Disagree

[ ] Neither agree nor disagree

[ ] Agree

[ ] Strongly agree

Thank you for completing this questionnaire. Your responses will be used to better understand the effect of the flipped classroom approach on students' academic achievement in electron configuration at Mankessim Senior High School in Ghana.

# APPENDIX F

INTRODUCTORY LETTER AND ETHICAL CLEARANCE FORM

UNIVERSITY OF EDUCATION, WINNEBA
FACULTY OF SCIENCE EDUCATION
DEPARTMENT OF CHEMISTRY EDUCATION
P. O. Box 25, Winneba, Ghana
chem@uew.edu.gh
+233 (020) 2041080

8th May, 2023

The Headmaster
Mankessim Senior High Technical School
Mankessim

Dear Sir,

**LETTER OF INTRODUCTION**
**ADDO FRANCIS KWADJO**

I write to introduce to you, Mr. Addo Francis Kwadjo who is pursuing an M.Phil in Chemistry Education in the Department of Chemistry Education, University of Education Winneba. He is undertaking a research project titled: **Effect of Flipped Classroom on Student's Academic Achievement in Electron Configuration at Mankessim Senior High Technical School** as his theses topic.

I would be very grateful if you could give him the necessary assistance he may require.

This is purely for academic purpose.

Thank you for your cooperation.

Yours faithfully,

**DR. EMMANUEL K. OPPONG**
**AG. HEAD OF DEPARTMENT**

## APPENDIX G

## SCAN COPY OF STUDENTS MARKED PRETEST, POST-TEST AND DELAYED

## PRE TEST

15/45

**UNIVERSITY OF EDUCATION WINNEBA**

**FACULTY OF SCIENCE EDUCATION**

**DEPARTMENT OF CHEMISTRY EDUCATION**

**ELECTRON CONFIGURATION DIAGNOSTIC TEST (ECDT)**

PRE-TEST

Purpose: This pre-test seeks to find out your conceptual understanding of electron configuration before flipped classroom approach (FCA) intervention. This exercise is being conducted for research purpose only because of this, marks obtained on the test will be treated confidentially. Thank you for your co-operation.

BIO-DATA OF THE RESPONDENT

GENDER: Male [✓] Female [ ] Age 15 - 17 [✓] 18 - 20 [ ]

Instruction

*This test consists of two sections; A & B. For section A, circle the correct option to each item, for B provide your candid answers in the spaces provided. Answer all the questions on this paper for 45 marks. Duration 50 minutes.*

SECTION A

[30 marks]

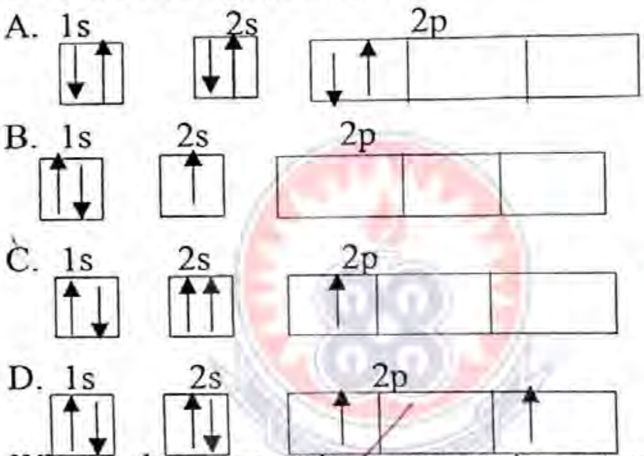
**MULTIPLE CHOICE QUESTIONS**

*Each correct answer attracts 1 mark*

1. The total number of electrons that can occupy the principal energy level is
   A. 2 B. 8 C. n D. $2n^2$
2. For an electron with angular quantum number $l = 2$, the magnetic quantum number can have
   A. An infinite number of values

B. Only one value
C. One of two possible values
D. One of five possible values

3. An electron cannot have the quantum numbers n =__, *l* =__ , m*l* __
   A. 2, 0, 0  B. 2, 1, 1  C. 3, 1, -1  D. 1, 1, 1
4. Which one of the following is an impossible subshell notation
   A. 4f  B. 2d  C. 3s  D. 2p
5. A 3p can have possible magnetic quantum number of values of
   A. 3 and 6  C. 3, 2 and 1
   B. -2, -1, 0 and 1  D. -1, 0 and 1
6. Which electronic configuration represents a violation of the Pauli's exclusion principle




7. What is the correct electronic configuration for $Mg^{2+}$
   A. $1s^2\,2s^2\,2p^6$  C. $1s^2\,2s^2\,2p^5\,3s^1$
   B. $1s^2\,2s^2\,2p^6\,3s^2$  D. $1s^2\,2s^2\,2p^4\,3s^2$
8. A certain transitional metal has an electron configuration such that its 4s orbital only has one electron. What would be a valid conclusion about this element
   A. This is an invalid electronic configuration because 4s orbital always contain two electrons in transitional metals
   B. The identity of the element is Manganese and it contain an empty 3d orbital
   C. The identity of the element is Chromium and it contain one electron in each 3d orbital

D. The identity of the element is Manganese and it contains one electron in each 3d orbital

9. An atom with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$ has an incomplete
   A. 2p sublevel    C. third principal energy level
   B. second principal energy level    D. 4s sublevel

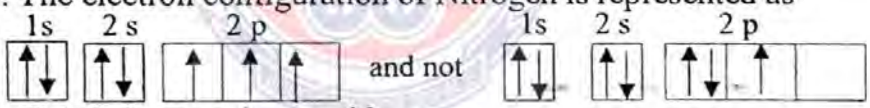
10. Pauli's exclusion principle is related to
    A. Quantum numbers of electrons
    B. Filling degenerate orbitals
    C. Filling the orbitals with lower energy first
    D. Quantity of electrons in the valence shell

11. The Bohr's model of the atom proposed the existence of
    A. The nucleus    C. Electron shells
    B. Nucleons    D. Neutrons

12. Which of the following species is represented by the electron configuration $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$
    A. Fe    B. Cr    C. Mn    D. Mo

13. How many orbitals are contained in an atom with atomic number 13
    A. 7    B. 6    C. 5    D. 13

14. The electron configuration of Nitrogen is represented as




This is in accordance with
    A. Quantum theory
    B. Pauli's Exclusion principle
    C. Hund's Rule of Maximum multiplicity
    D. Aufbau principle

15. Which of the following statements is true
    A. An electron in an n = 1 shell has lower energy than an electron in an n =2 shell
    B. All subshells contain same number of electrons
    C. The number of subshells within a shell is equal to the orbital number
    D. All subshells have an identical shape and size

16. Which electron configuration represents an atom in an excited state?
    A. $1s^2 2s^2 2p^6 3p^1$ C. $1s^2 2s^2 2p^6 3s^2 3p^2$
    B. $1s^2 2s^2 2p^6 3s^2 3p^1$ D. $1s^2 2s^2 2p^6 3s^2$
17. Which sublevel electron configuration correctly represents a completely filled third principal energy level?
    A. $3s^2 3p^6 3d^8$ C. $3s^2 3p^6 3d^{10}$
    B. $3s^2 3p^2 3d^{10}$ D. $3s^2 3p^6 3d^5$
18. All of the elements in Period 3 have a total of 2 electrons in the
    A. 2s sublevel C. 2p sublevel
    B. 3s sublevel D. 3p sublevel
19. Which atom in the ground state contains a partially filled 3p orbital?
    A. Argon B. Calcium C. Potassium D. Aluminum
20. Which atom in the ground state has three unpaired electrons in its outermost principal energy level?
    A. Li B. B C. N D. Ne
21. In the ground state, the atoms of elements in Period 2 all have the same number of
    A. Protons B. Neutrons C. 1s electrons D. Oxidation state
22. What is the total number of valence electrons in an atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?
    A. 6 B. 3 C. 2 D. 5
23. Which element has a completely filled third principal energy level?
    A. Ar B. Ne C. Fe D. Zn
24. A maximum of 6 electrons can occupy a/an
    A. *s* orbital B. *s* sublevel C. *p* orbital D. *p* sublevel
25. Which of the following represents the electron configuration of the outermost principal energy level of a Group 15 element in the ground state?
    A. $s^2p^3$ B. $s^2p^5$ C. $s^1p^3$ D. $s^1p^5$
26. In the ground state, which element's atoms have five completely filled orbitals?

A. Li B. B C. C D. Ne

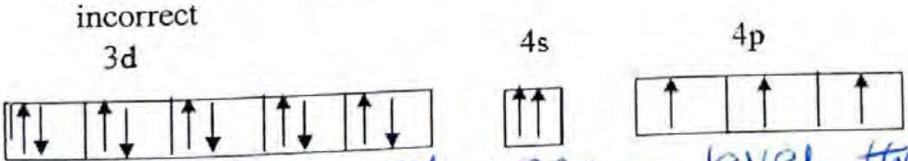
27. An atom with the electron configuration of $1s^22s^22p^63s^23p^63d^54s^2$ has an incomplete
    A. $2p$ sublevel
    C. third principal energy level
    B. second principal energy level
    D. $4s$ sublevel
28. Which electron transition represents the release of energy?
    A. $1s$ to $3p$ B. $2s$ to $2p$ C. $3p$ to $1s$ D. $2p$ to $3s$
29. How does the ground state electron configuration of the hydrogen atom differ from that of a ground state helium atom?
    A. Hydrogen has one electron in a higher energy level.
    B. Hydrogen has two electrons in a lower energy level
    C. Hydrogen contains a half-filled orbital
    D. Hydrogen contains a completely filled orbital
30. Which of the following represents the electron configuration of an isotope of oxygen in the ground state?
    A. $1s^22s^22p^1$
    C. $1s^22s^22p^3$
    B. $1s^22s^22p^2$
    D. $1s^22s^22p^4$

[15 marks]

## SECTION B

***Answer all the questions in this section. All answers should be written in the spaces provided.***

31. Explain why the ground state electron configuration stated below is incorrect




From the principal of energy level the electron configuration must be of opposite spin.

[ 1 mark]

32. Indicate the reason why the ground state electron configuration below is incorrect

| 3d | | | | | | 4s | | 4p | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | | ↑↓ | | ↑↓ | | |

From the 4p orbital it must be filled Single before ~~adding~~ ~~double~~ adding opposite spin.

[1 mark]

33. Use the s,p,d and f electron configuration notation of $_{16}$**S** to identify its period and group number

~~Group two (2)~~ and Period two (2).
and group Six(6).

[2 marks]

34. Write the electron configuration of $_{29}$**Cu** and use it to determine the number of unpaired electrons

$1s^2\ 2s^2\ 3p^6\ 4s^2\ 4p^6\ 5s^2\ 4d^4\ 5p^4$

[1 mark]

35. Explain the meaning of $5d^6$ as applied in electron configuration

It is a d orbital and has 6 ~~atomic~~ atomic number and is at the 5th energy level.

[3 marks]

36. Write the electron configuration of $_9$**F-**

$1s^2\ 2s^2\ 3p^6$

[1 mark]

37. Write the electron configuration of ***Iron*** (Z=26) after donating two electrons

$1s^2\ 2s^2\ 3p^6\ 4s^2\ 4p^6\ 5s^2\ 4d^4$

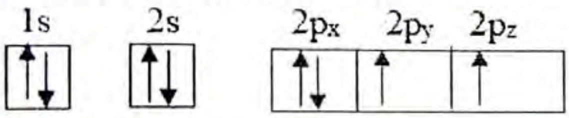
[2 marks]

38. Give the detail electron configuration of $_{24}Cr$

1S 2S 3Px y z ~~4S~~ 4Px y z 5S 4d

[1 mark]

39. Explain the significance of the ***arrows*** and letters ***x, y and z*** in the given electron configuration below




The arrows signify the ~~ø~~ number of electron and the x, y and z signifies sub shells

[2 marks]

40. How many electrons can be accommodated in a set of *f* orbitals

Two (2)

[1 mark]

# POST-TEST SCRIPTS

38/45

UNIVERSITY OF EDUCATION WINNEBA

FACULTY OF SCIENCE EDUCATION

DEPARTMENT OF CHEMISTRY EDUCATION

## ELECTRON CONFIGURATION ACHIEVEMENT TEST (ECAT)

POST-TEST (1)

Purpose: This post-test seeks to find out your conceptual understanding of electron configuration after flipped classroom approach (FCA) intervention. This exercise is being conducted for research purpose only because of this, marks obtained on the test will be treated confidentially. Thank you for your co-operation.

BIO-DATA OF THE RESPONDENT

GENDER: Male [✓] Female [ ] Age 15 - 17 [✓] 18 - 20 [ ]

Instruction

*This test consists of two sections; A & B. For section A, circle the correct option to each item, for B provide your candid answers in the spaces provided. Answer all the questions on this paper for 45 marks. Duration 50 minutes.*

SECTION A [30 marks]

### MULTIPLE CHOICE QUESTIONS

*Each correct answer attracts 1 mark*

1. A certain transitional metal has an electron configuration such that its *4s* orbital only has one electron. What would be a valid conclusion about this element

A. This is an invalid electronic configuration because *4s* orbital always contain two electrons in transitional metals

B. The identity of the element is Manganese and it contain an empty *3d* orbital

C. The identity of the element is Chromium and it contain one electron in each *3d* orbital

D. The identity of the element is Manganese and it contains one electron in each *3d* orbital

2. An atom with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$ has an incomplete

   A. 2p sublevel
   B. second principal energy level
   C. third principal energy level
   D. 4s sublevel

3. Aufbau's principle is related to

   A. Quantum numbers of electrons
   B. Filling degenerate orbitals
   C. Filling the orbitals with lower energy first
   D. Quantity of electrons in the valence shell

4. Which of the following species is represented by the electron configuration $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^6$ $4s^2$

   A. Fe B. Cr C. Mn D. Mo

5. How many orbitals are contained in an atom with atomic number 13

   A. 7 B. 6 C. 5 D. 13

6. Which of the following statements is true

   A. An electron in an n = 1 shell has lower energy than an electron in an n =2 shell
   B. All subshells contain same number of electrons
   C. The number of subshells within a shell is equal to the orbital number
   D. All subshells have an identical shape and size

7. Which sublevel electron configuration correctly represents a completely filled third principal energy level?

   A. $3s^2 3p^6 3d^8$ B. $3s^2 3p^2 3d^{10}$ C. $3s^2 3p^6 3d^{10}$ D. $3s^2 3p^6 3d^5$

8. All of the elements in *Period 3* have a total of 2 electrons in the

   A. $2s$ sublevel B. $3s$ sublevel C. $2p$ sublevel D. $3p$ sublevel

9. Which atom in the ground state contains a partially filled $3p$ orbital?

   A. Argon B. Calcium C. Potassium D. Aluminum

10. Which atom in the ground state has two unpaired electrons in its outermost principal energy level?

A. Li B. O C. N D. Ne

11. In the ground state, the atoms of elements in Period 2 all have the same number of

A. Protons B. Neutrons C. 1s electrons D. Oxidation state

12. What is the total number of valence electrons in an atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?

A. 6 B. 3 C. 2 D. 5

13. Which element has a completely filled third principal energy level?

A. Ar B. Ne C. Fe D. Zn

14. A maximum of 10 electrons can occupy

A. a *d* sublevel B. an *s* sublevel C. a *d* orbital D. a *p* sublevel

15. Which of the following represents the electron configuration of the outermost principal energy level of a Group 15 element in the ground state?

A. $s^2p^3$ B. $s^2p^5$ C. $s^1p^3$ D. $s^1p^5$

16. In the ground state, which element's atoms have five completely filled orbitals?

A. Li B. B C. C D. Ar

17. An atom with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ has an incomplete

A. $2p$ sublevel
B. second principal energy level
C. third principal energy level
D. $4s$ sublevel

18. Which electron transition represents the release of energy?

A. $4p$ to $3s$ B. $2s$ to $2p$ C. $3p$ to $3s$ D. $2p$ to $3s$

19. Which of the following represents the electron configuration of an isotope of Sulphur in the ground state?

A. $1s^2 2s^2 2p^6 3s^2 3p^4$ B. $1s^2 2s^2 2p^2 3s^2 3p^6$

C. $1s^2 2s^2 2p^6 3s^2 3p^3$ D. $1s^2 2s^2 2p^4 3s^2 3p^4$

20. How many orbitals are in d sub shell
    A. 7 B. 5 C. 3 D. 1
21. Which of the following ions has the same electron configuration as argon?
    A. $Na^+$ B. $Mg^{2+}$ C. $K^-$ D. $Ca^{2+}$
22. Which of the following statements is true regarding the electron configuration of an atom in its ground state?
    A. The electron configuration of an atom in its ground state is always the same as its electron configuration in an excited state
    B. The electron configuration of an atom in its ground state is the arrangement of electrons in the lowest energy levels and sublevels
    C. The electron configuration of an atom in its ground state is the arrangement of electrons in the highest energy levels and sublevels
    D. The electron configuration of an atom in its ground state is determined by the number of neutrons in the atom.
23. For an electron with angular quantum number $l = 0$, the magnetic quantum number can have
    A. An infinite number of values C. One of two possible values
    B. Only one value D. One of five possible values
24. Which of the following is the correct electron configuration for a carbon atom in its excited state?
    A. $1s^2 2s^2 2p^2$ B. $1s^2 2s^1 2p^3$ C. $1s^2 2s^2 2p^3$ D. $1s^2 2s^2 2p^4$
25. A 5p can have possible magnetic quantum number of values of
    A. 5 and 6 B. -2, -1, 0 and 1 C. 3, 2 and 1 D. -1, 0 and 1
26. The valence electrons in $_5B$ are in the
    A. 1s orbital B. $2p_x$ orbital C. 2s orbital D. 2p orbital
27. What is the electron configuration of ***Iron*** ion with a charge of +2?
    A. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$ C. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$
    B. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ D. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$
28. Which one of the following is an impossible subshell notation
    A. 4f B. 2s C. 2d D. 3p

29. Which of the following elements has a completely filled 2p subshell in its ground state?
    A. N  B. O  C. F  D. Ne

30. Which of the following subshells has the highest energy?
    A. 3s  B. 5f  C. 4d  D. 2p

SECTION B [15 marks]

***Answer all the questions in this section. All answers should be written in the spaces provided.***

31. State with reason if the ground state electron configuration stated below is correct or incorrect

| 3d | | | | | | 4s | | 4p | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | | ↑ | | ↑ | ↑ | ↑ |

The above configuration is correct.

[ 1 mark]

32. Indicate with reason if the ground state electron configuration below is correct or incorrect

| 3d | | | | | | 4s | | 4p | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ↓↑ | | | | |

The above configuration is correct because it has Obeyed the Aufbau rule.

[1 mark]

33. Use the s, p, d and f electron configuration notation of $_{15}P$ to identify its period and group number

$_{15}P$

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

[2 marks]

~~Period~~ Period – 5 (2+3)
Group – 3

34. Write the electron configuration of **oxide ion** and use it to determine the number of unpaired electrons

$_8O^{2-} \rightarrow 1s^2\ 2s^2\ 2p^6$. There are 0 unpaired electrons

[2 mark]

35. Explain the meaning of $4f^7$ as applied in electron configuration [3 marks]

This means there are seven electrons in the f sublevel of the 4th energy level / shell.

36. Write the electron configuration of $_8O^{-2}$ [1 mark]

$1s^2\ 2s^2\ 2p^6$

37. Write the electron configuration of ***copper*** (Z=29) after donating two electrons [1 mark]

$_{29}Cu^{2+} \rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^7$

38. State the reason(s) why the correct electron configuration of $_{24}$**Cr** written as $_{18}[Ar]4s^1 3d^5$ do not violate Aufbau principle. [1 mark]

~~It~~ It doesn't violate Aufbau rule because to make the whole configuration stable, an electron is gained from 4s to make 4s and 3d halvely filled and stable.

39. What does the ***arrows*** and letters ***x, y and z*** represent in the given ground state electron configuration of $_9F$

| 1s | 2s | $2p_x$ | $2p_y$ | $2p_z$ |
|---|---|---|---|---|
| ↓↑ | ↓↑ | ↓↑ | ↓↑ | ↑ |

The arrows represent the electron spin and letters x, y and z represents the ~~atom~~ electron's direction in these axes in the atom.

[2 marks]

40. How many electrons can be accommodated in a $p_x$ orbital? [1 mark]

2 electrons, maximum.