UNIVERSITY OF CAPE COAST

COMPARISON OF DIAGRAMS AND MODELS USED FOR TEACHING ATOMIC ORBITALS IN THE SENIOR SECONDARY SCHOOL

BY

DANIEL KOFI OSEI-OWUSU

Thesis submitted to the Department of Science and Mathematics Education of the Faculty of Education, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy

Degree in Science Education

NOVEMBER, 2007

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:............................... Date: 22nd Dec., 2008.

Name: Daniel Kofi Osei-Owusu

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature .... Date 23/12/08

Name: Prof. F. S. K. Tayman

Co-Supervisor's Signature .... Date: 22/12/08

Name: Dr. Joseph Ghartey Ampiah

ABSTRACT

This thesis is a report on a comparative study of diagrams and models used as teaching aids in teaching atomic orbitals in senior secondary schools (SSS). An orbial represents a three-dimensional volume of space around an atomic nucleus, where electrons are found. Diagrams of orbitals in textbooks and on teachers' chalkboards appear in two dimensions, making visualization difficult for students.

Three second-year elective chemistry classes in different schools in the Cape Coast Municipality were pretested on atomic orbitals. They were then taught the concept of atomic orbital, using diagrams only, models only, and a combination of diagrams and models respectively as teaching aids. Finally, they were posttested on the concept.

Analysis of covariance (ANCOVA) on the posttest scores of the students, using their pretest scores as covariate, ranked the teaching aids in the order: "models only", "diagrams and models" and "diagrams only". A McNemar chi-square test on changes in students' misconceptions from the pretest to the posttest showed that the "models only" class had the highest significant proportional decrease in misconceptions, whilst the "diagrams only" class had the least.

It is therefore concluded that the use of models only as teaching aids is more effective than the use of diagrams only in enhancing SSS students' visualization of atomic orbitals. Moreover, combination of diagrams and models confuses students and hampers their visualization. Suggestions have therefore been made in the thesis for appropriate bodies to emphasize the use of models in teaching atomic orbitals to SSS students.

ACKNOWLEDGMENTS

I am very grateful to Prof. F. S. Tayman and Dr. J. Ghartey Ampiah for their critical attention and guidance in supervising the research that led to the writing of this thesis and the presentation of the report in the thesis. I also appreciate the skills of Mr. Appiah of Cape Coast Technical Institute in the development of the physical models of atomic orbitals for teaching during data collection. I further thank Miss Evelyn Otiwaa for neatly typing the report for me.

DEDICATION

To my wife Helena and my children Emmanuel, Samuel, Comfort, Grace and Dora.

TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Background to the Study

According to Johnson-Laird as cited in Borges and Gilbert (1999), people must have a "working model" of any phenomenon or state of affairs in order to understand it. Also, the ability to give explanations is intimately tied to such understanding. Borges and Gilbert have therefore indicated that people enhance their understanding of phenomena by having mental models of them. According to them, mental models are internal representations of objects, a state of affairs, a sequence of events or processes. In their view, such models enable people to give explanations, make decisions and control their execution. Mental models are therefore widely used in the sciences (Harrison & Treagust, 1996; Snyder, 2000); and Clement (2000) and Alves, Colinvaux, de Barros, Franco, Krapas and Queiroz (1999) have advocated research into such models. Gilbert (1994) has described models in general as important tools for the teaching and learning of science. In his view, the progress of science is normally marked by the production of a series of models, modelling being a major element in scientific methodology.

According to De Jong and Van Driel (2001), Gilbert and Justi (2000, 2001) and Zimmermann (2000), however, one of the greatest challenges for science teachers is the use of models. Owing to the lack of use of models by teachers, many science topics look abstract to students (Fischler & Siefert, 2001; Harrison & Treagust, 2000; Hawkes, 1996; Van Driel & Verloop, 1999). For students to understand concepts taught, Brown, Clement and Zietsman (as cited in Borges & Gilbert, 1999) have emphasized the need for teachers to use intuitive or simple models. In the view of Brown, et al, such models bridge the gap between what students already know and the new material being taught. Boulter and Gilbert (1995) have also suggested the development of appropriate teaching models by teachers because of their impact on learners' ideas about subject matter.

In Ghana, there have been conferences and workshops organized by the Ghana Association of Science Teachers (GAST) at which the use of appropriate teaching aids has been emphasized. Teacher trainees in teacher training colleges and universities are helped to develop and use teaching materials to help them explain concepts to their students. However, many Ghanaian science teachers have been teaching without using appropriate teaching aids, perhaps as a result of the difficulty in developing such aids. Hence, many science concepts look abstract to students (Harrison & Treagust, 2000; Van Driel & Verloop, 1999).

One such concept, which seems abstract to Ghanaian SSS students, is the atomic orbital (Darkwa, 1999). Students seem not to be able to visualize it. Some of them do not see any differences between an orbital and a shell, and they use the two terms interchangeably (Darkwa, 1999). This suggests that teachers must find ways and means of helping students to understand the distinction between the two concepts. It has been suggested that three-dimensional teaching aids (such as models of atoms) tend to lead to greater understanding and retention of key ideas by students, compared with two-dimensional teaching aids such as diagrams (Eaton et al, 2001). There is therefore the need to explore the teaching of abstract concepts by using such relevant teaching aids in Ghana.

Statement of the Problem

The researcher's interaction with students from a number of senior secondary schools (SSS) in Ghana has revealed that students consider atomic orbitals as an abstract topic. Whereas some SSS students mentioned the shape and orientation as the aspects of an orbital that they could not easily visualize, others stated that they could not imagine the opposite spins of an electron-pair in an orbital.

The SSS chemistry syllabus introduces students to both the shape and orientation of the s- and p-orbitals (Ministry of Education [MOH], 2003). However the existing knowledge of atomic orbitals observed in textbooks (e.g. Ameyibor & Wiredu, 1995; Brown, 1984; Chang, 1998; Kask & Rawn, 1993; Olmsted & Williams, 1994) is found to cover the way the concept originated, the wave function that describes the probability of finding an electron in an orbital, and the type, shape and orientation of the orbital. The existing knowledge also covers the number of orbitals of each type in a given shell or sub-shell, as well as the number of electrons that can be accommodated by a single orbital.

However, the textbooks or posters do not show clearly enough the shapes and spatial orientations of the orbitals. The pages and poster surfaces are two-dimensional and so cannot show clearly the three-dimensional nature of an orbital. Hence, students may find a gap between reading and visualization. It appears the diagrammatic and pictorial representations of orbitals found in textbooks and on posters do not adequately represent the picture of the orbital, even though teachers draw these diagrams and pictures on their chalkboards to promote the development of mental models of orbitals. The chalkboards, just like the pages of the books and the surfaces of the posters, are only two-dimensional and do not show the three-dimensional characteristic of an orbital adequately. Indications are that there is misunderstanding of atomic orbitals due to inadequate visualization of the orbitals. This suggests that teachers must devise other ways and means of helping their students develop the correct mental models of what they teach, in order to enhance their understanding (Gil, 2001).

Darkwa (1999) has also suggested that the teaching of the nature of the atom and the properties of electrons should be reinforced by the use of physical models, in order for students to build the right mental picture of the atom. It would therefore be appropriate for a study to be carried out comparing the use of diagrams, physical models and their combination to ascertain the impact each has on students' understanding of atomic orbitals.

Purpose of the Study

The purpose of this study therefore was to compare the effectiveness of the use of physical models of the s-and-p-orbitals, that of diagrams of those orbitals and of a combination of models and diagrams as teaching aids for helping SSS students understand the concept of atomic orbitals and the visualization of their shapes and orientations. The study attempted to find out whether there were statistically significant difference in performance among three selected groups of students in a given test on atomic orbitals before and after they had been taught by the use of these different sets of teaching aids.

Research Question and Hypotheses

One research question and two null hypotheses (H_o) were formulated for the study as follows:

1. What misconceptions about atomic orbitals do students have before and after they are instructed using the various treatments?
2. There is no significant difference among the posttest mean scores of student groups, which are taught the concept of atomic orbital using diagrams only, models only, and a combination of diagrams and models.
3. There are no significant changes in misconceptions about atomic orbitals for student groups, which are taught using diagrams only, models only, or a combination of diagrams and models.

Limitations

This study was not purely experimental as it was impossible to randomize students to the experimental and control groups. However, the selection of schools by simple random sampling makes the study quasi-experimental and may limit its generalizability.

Also, time and financial constraints did not allow for more schools to be selected. However, the schools selected are typical of most SSS in Ghana; and the chemistry students used in this study are not different from chemistry students in other schools. The findings of the study could therefore be applicable to chemistry students outside the sample of this study.

Significance of the Study

The study is significant for a number of reasons. First, it investigated the effects of the types of teaching aids teachers use on students' visualization and understanding of an abstract concept such as the atomic orbital. The outcome of the investigation can be shared with science teachers at conferences and workshops.

The findings of this study will stimulate further research on ways of helping students to visualize other abstract concepts. This will enhance curriculum development, which never ends (Oliva, 1992).

Suggestions have therefore been offered to curriculum developers to bring innovations into the curriculum. Ultimately, students will benefit from the suggested methods of helping them visualize atomic orbitals.

Organization of the Rest of the Thesis

The second chapter is devoted to a review of the literature relevant to the study. In the chapter, the word "model" is explained, and different types of models are given by a number of researchers. Moreover, the role of models in the teaching-learning process, learners' preferred mental models and their implications on teaching are discussed. The chapter also reviews the content of the SSS syllabus about atomic orbitals and the content knowledge of atomic orbitals in textbooks. Finally, implications of the literature review on the study are discussed.

The third chapter deals with the methodology used for the study. It discusses the research design, population and sample. It also presents a discussion of the instrument for data collection and how it was developed and pilot-tested. Furthermore, the chapter describes the procedure for the study. The lesson plans used to teach the students are also presented.

The fourth chapter presents the results of the study and discussions on them. The analytical tools presented in the chapter are the analysis of covariance (ANCOVA) test for differences in posttest mean scores among student groups, and the McNemar chi-square test for changes in students' misconceptions in each group. The types of misconceptions students showed in each test are also discussed qualitatively.

In the fifth chapter, an overview of the research problem and methodology is given. A summary of the key findings and their interpretations with reference to the literature are then presented. A conclusion is drawn, recommendations are made and suggestions, given for future research.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Understanding of the shapes and orientations of atomic orbitals and opposite spins of the electron pair in an orbital is not an end in itself. It is rather helpful to the understanding of the structure of an atom, the properties of the elements and the way chemical bonds are formed and broken. The breaking of bonds and the formation of new ones are also the phenomena involved in chemical reactions (Chang, 1998; Kask & Rawn, 1993; Olmsted & Williams, 1994). Thus, the understanding of the concept of atomic orbitals occupies a significant position in the study of chemistry. This understanding, in the view of Johnson-Laird, as cited in Borges and Gilbert (1999) can only be achieved by learners when they have a working model. According to Borges and Gilbert, in the past only philosophers addressed models and model-based reasoning. Educational psychologists and science education researchers only recently began to address the use of models in education (Mayer, 1992; Gilbert, 1994). This means that the role of models in the learning process, and how they may be developed and used, are familiar only to a few educators. Against this background, this chapter reviews some studies that have addressed the importance of models in the teaching and learning of science. Additionally, the chapter reviews the SSS chemistry syllabus on atomic orbitals, and the content knowledge of orbitals as found in textbooks.

Theoretical framework of the Study

Brown, Clement and Zietsman, as cited in Borges and Gilbert (1999), have emphasized the need for "bridging conceptions" in the teaching of concepts to students. By this they mean that teachers must start the teaching of concepts by using intuitive or simple models that even young students can accept, and help them to build upon such models to acquire more developed ones. In the view of Borges and Gilbert, the early introduction of the more developed models creates an overload for learners because many processes are involved even in simple situations. According to Boulter and Gilbert (1995), teachers must be able to develop and choose appropriate models for use in the classroom because they have an impact on the children's ideas about the subject matter. These ideas have stimulated a quasi-experimental study about how the teaching of the concept of atomic orbitals can be simplified for SSS students to grasp. The quasi-experiment has been so designed as to compare the impact of diagrams, that of models, and of a combination of both of them as teaching aids on students' understanding of atomic orbitals.

Models

According to Gilbert (1994), a model is a representation of an object, an event or an idea, and it creates a vehicle through which what it represents can be conceptualized and understood. In his view, models are important in science teaching because they are major tools for teaching and learning, each of them associated with a distinctive theory.

Gilbert (1998) has identified five types of models namely:

1. Mental Models – models that are visualized in the mind;
2. Expressed Models – ways in which a person tries to explain or present their mental models;
3. Consensus Models – expressed models which have gained acceptance within the scientific community;
4. Historical Models – consensus models which have been superseded by other models that are more scientific;
5. Teaching models – models specifically produced to teach difficult consensus or historical models.

Later publications by Boulter, Elmer and Gilbert (2000), Coll and Treagust (2002a, 2002b) and Boulter, Gilbert and Rutherford (2000) have explained that a model becomes a scientific one after passing through the stages of an expressed model and a consensus model respectively. These stages are explained in more details under mental models.

Mental Models

Glynn and Russell (1997) have stated that children, on learning a concept meaningfully, build mental models of it, just as scientists do. They have cited Pauling as having remarked that the greatest value of models is in their contribution to the process of originating new ideas. According to Glynn and Russell, Pauling's most important "laboratory" has been in his mind, for in it he has created mental models leading to the development of physical models of the structure of protein.

In the view of Greca and Moreira (2000) and Harrison and Treagust (2000), scientists and learners construct mental models to interpret their experiences and to make sense of the physical world. Borges and Gilbert (1999) have pointed out that the notion of a mental model has been used in different areas of research with different meanings. They have argued that some researchers regard it only as a representation of some aspects of the world, whilst others regard it as an analogue of objects in the world. According to them, whereas the first sense is pragmatic, it is also weak since it does not consider the origin of the model, or how it affects thinking about the issue it represents. In their view, however, the second sense is stronger because it implies that a mental model represents an aspect of an external reality. Thus, they have stated that mental models serve as a means by which one can explain the relationship between one's cognitive activity and the world, and are therefore unstable, naturally evolving and incomplete. Boulter and Gilbert (1995) share this view and have stated that the construction of a mental model of a given system involves the selection of only some parts of the system and the relationships between them for representation.

In the view of Coll and Treagust (2002b), despite the incomplete and unstable nature of mental models, they facilitate description, explanation and prediction, as argued by Gilbert and Rutherford (1998a, 1998b) and Boulter, Elmer and Gilbert (2000). Coll and Treagust have also argued that while the users of these models must use them to explain concepts to other people, those to whom the concepts are explained, must also use the models to understand them. This is transfer of mental models. Duit and Glynn (1995) however, have argued that mental models represent mental constructs and are therefore unique to the observer; thus, it is difficult for anyone to uncover another person's mental models, because some people may act in ways inconsistent with their beliefs. This argument gains support from the statement of Viennot (1994) that individuals can hold different mental models, which they use to cope with events and states of affairs.

Stages of a Mental Model

Despite the argument that mental models are unique to the observer, available literature indicates that they can develop into stages at which they become public and gain universal acceptance. The way this can happen has been indicated in four of the five types of models identified by Gilbert (1998). A mental model, which is the first stage, is presented by the individual having it, so that it becomes exposed to the public as an expressed model. After the scientific community has accepted it, it evolves into a consensus model. The consensus model can become a teaching model, which is used to teach difficult concepts or explain other concepts. Thus, Boulter, Elmer and Gilbert (2000) have explained that in spite of the private and personal nature of a mental model, it can be made public, thereby becoming an expressed model. According to Gilbert's explanation, not only does it become an expressed model; it can also become a consensus or teaching model. It is then that the public can use it, as indicated by Coll and Treagust (2002b). According to Boulter, Gilbert and Rutherford (2000), after experiments and discussions have shown that the expressed model is of value it becomes a consensus model. Coll and Treagust have also explained that a consensus model is subjected to rigorous experimental testing and that, after surviving many of such tests, it is accepted as a scientific model. Thus, in the view of Chalmers (1999), although mental models are personal and subjective, they can be widely accepted by the scientific community and become part of the peer-negotiated, public language of science, thereby possessing a socially accepted meaning.

Differences between Experts and Novices in the Use of Mental Models

According to Coll and Treagust (2002b), research in science education has shown that experts and novices have different views of mental models. For instance, in the view of Clement (1998) and Grosslight, Jay, Smith and Unger (1991), experts can be distinguished from novices by their pragmatic use of mental models that are known to possess limitations. Abraham and Williamson (1995) have related this to experts' greater ability to visualize abstract concepts. Reiner (2000) has also explained that experts, unlike novices, conduct thought experiments by manipulating and evaluating their mental models. Borges and Gilbert (1999) have indicated that experts differ from novices in seeing mental models in a functional, utilitarian manner, recognizing that they are meant to serve the user and, therefore, frequently need modification as new experimental data are revealed.

Chittleborough, Mamiala and Treagust (2001) have stated that scientists and competent modelers are able to communicate with each other without any confusion arising. Novices however, get confused when scientists and teachers communicate with them, for the images possessed by the scientists are abstract and are not of real world objects (Coll & Treagust, 2002b). Studies done by Gilbert and Rutherford (1998a, 1998b) have shown that experts, unlike novices, use mental models for a variety of purposes such as the production of simpler forms of objects or concepts, the provision of stimulation and support for the visualization of some phenomena, and the explanation of scientific phenomena.

Palmer (1999, 2001) has observed that students maintain several models in their minds, some of them being scientific and others, unscientific. The result is that their minds are exposed to contradictory models, which lead to confusion. Nevertheless, Borges (1996) has shown that with time learners extend the scope of their models, improve upon the differentiation of basic concepts, adopt richer vocabulary and use more abstract notions. In the view of Chi, De Leew and Slotta (1994), new ontological entities are introduced into the models, and learners reclassify their ontological status of existing entities. Thus, according to Borges and Gilbert (1999), learners are able to tell more complete and sophisticated stories about phenomena in a particular domain. It follows, as indicated by Driver, Leach, Scott and Wood-Robinson (1994) that only with deliberate instruction can learners adopt sophisticated models, their adoption aided by the initial use of simpler models. Hence, according to Gilbert and Rutherford (1998a, 1998b), teachers must find ways of helping students to select scientific and effective models for their studies, starting with simpler ones.

Learners' Preferred Mental Models

According to Eshach and Garik (2001), learners prefer simple mental models to complex ones. Also, studies by Pereira and Pestana (1991) on high-achieving Portuguese learners' mental models of water, and a survey by Harrison and Treagust (1996) on Australian senior secondary school (SSS) students' mental models of atomic structure reveal that learners like realistic-appearing models such as space-filling ones. Moreover, Taber (1998) has found that British Advanced Level students prefer a simple mental model like the octet rule to the molecular orbital theory for covalent compounds. Undocumented observation of SSS students in a number of schools in Ghana by the researcher has shown their preference for the interchange of valencies between elements to the balancing of oxidation numbers when writing the chemical formulae of compounds. It has also been observed that Ghanaian SSS students prefer the outermost octet and $2n^2$ rules to the use of the Aufbau Principle when writing the electronic configuration of an element. Thus, students stick to Dalton, Rutherford and Bohr's classical model of the atom even when they have been taught the more modern wave-mechanical concept (Darkwa, 1999).

Coll and Treagust (2002b) carried out a study on secondary, undergraduate and graduate chemistry students in New Zealand to investigate their preferred mental models for the concept of covalent bonding. They were particularly interested in finding out whether or not exposure to complex mental models in their chemistry education would show up in their patterns of preference and use of models in interpreting common physical properties and phenomena. For the purpose of data collection they examined students' lesson plans, lecture notes, textbooks and workbooks, and also interviewed them. The study showed that students preferred simple, realistic mental models, despite the understanding of some complex and mathematically sophisticated mental models observed in some of them (Taber, 1995, 1997, 2000, 2001).

According to Coll and Treagust (2002b), although it had been many years since the graduate chemistry students in their study were exposed to instruction by the use of simple models, they stuck to them and used the ideas from more complex models only when their simpler explanations broke down. Coll (1999a, 1999b), Coll and Taylor (2001a, 2001b) and Coll and Treagust (2000, 2001a, 2001b, 2002a) have made a similar observation during their investigation of learners' mental models of metallic, chemical and ionic bonding, and their use of analogies and alternative conceptions for chemical bonding.

Through interviews with Brazilian 15 to 17 year-old secondary school students and professionals whose daily jobs involved electricity, Borges and Gilbert (1999) discovered that they strongly adhered to mental models of electricity, which helped them to perform their functions easily. One of such models is that a current is a flow of energy or electricity through a circuit. In the view of Borges and Gilbert, holders of this model were characterized by poor differentiation of current, energy, electricity and voltage, although they were able to identify a complete circuit as a requirement for the current. Another model identified is that a current is energy or electricity flowing from both terminals of a battery to a bulb in its circuit. Thus, the model assumes positive and negative currents travelling along separate wires and meeting in the bulb to produce heat and light. A third model identified is that a current consists of electric charges in motion through a conductor, a battery producing energy to be delivered to the charges by means of a chemical reaction. According to this model, the energy supplied by the battery keeps the charges in their motion. In the view of Borges and Gilbert, all these three models are based on alternative conceptions. Harrison and Treagust (1996) and Duit and Pfundt (1994,

1997) have also observed strong adherence to alternative conceptions and simplistic mental models among students in general, and their observation gives support to Borges and Gilbert's view about the mental models of their Brazilian secondary school students.

Borges and Gilbert (1999) identified a fourth model of electrical current among Brazilian physics teachers and few technical school students. This model, unlike the first three, differentiates electrical current from energy, describing the former as the movement of electrically charged particles under the action of a potential difference. According to the model, a battery maintains a difference in potential between its terminals, creating an electric field to cause electric charges to move along a conductor. The model also observes a current as circulating only in a closed circuit and being conserved. Moreover, it recognizes the bipolarity of the components of the circuit.

From the interviews, Borges and Gilbert (1999) observed a pattern of changes along several dimensions in the individuals' mental models over time. According to them, people show changes in the scope and limitations of their models, adopting richer vocabulary and using more abstract notions.

Implications of Learners' Preferred Mental Models on Teaching

The observations about learners' preferred mental models suggest that in explaining concepts, students do not want to use complex mental models. Rather, it is simple models that they want to use. A study conducted by Coll and Treagust (2002b) showed the adherence to simple models by secondary, undergraduate and graduate students in New Zealand when explaining concepts. Coll (1999b), Coll and Treagust (2000, 20001a, 2001b), Gillespie, Moog and Spencer (1996a, 1996b), Ogilvie (1990) and Tsaparlis (1997) have therefore suggested that there is little point in teaching complex and abstract mental models like the molecular orbital theory at the high school or introductory (freshman) tertiary level. They share this view with Coll and Treagust (2002b), who have stated that the octet rule should be taught at the high school level whilst the molecular orbital theory is taught to students specializing in Advanced Level chemistry that will utilize that theory in their research.

The differences between the views of experts and novices about mental models suggest that there must be studies to find ways of helping beginners to visualize concepts taught (Gilbert & Rutherford, 1998a, 1998b). Such studies should help science (especially chemistry) teachers to develop or use mental models that will be understood by their students, so that the teaching process becomes smooth.

Drawing of Mental Models

The drawing of mental models is a dynamic method used by exemplary teachers to help children understand scientific concepts (Glynn & Russell, 1997). According to Glynn and Russell, the students of exemplary teachers like Sampson, Wayne, Carter and Bourdeau drew diagrams to represent their mental models of molecules, cells, waves and planets respectively. They have explained that drawings open windows into students' minds, allowing teachers to examine their mental models of scientific concepts.

Physical Models

Gylnn and Russell (1997) have observed that some teachers use physical models to show their students simplified representations of concepts. They have also pointed out that students, after drawing valid diagrams of mental models, can use their drawings to build physical models. It therefore follows from the classification of models by Gilbert (1998) that physical models are expressed models, for they present or explain the mental models of teachers, students and other people who use them. For instance, according to Glynn and Russell, Conti's students, during a lesson on insects, drew their mental models of the insects and used their drawings to build physical models of them. They have explained that this lesson was divided into three steps namely drawing from observation, working in groups to build the physical models and, finally, presenting and discussing the models. According Glynn and Russell, Conti and his students observed some local insects they had collected, and discussed their structural and functional features. In the discussion, Conti used enlarged pictures and diagrams to point out small features on the insects. Then he removed the insects, pictures and diagrams from their sight and asked the students to draw and label their mental models of them. He discussed the drawings with them, pointing out valid and invalid features. Glynn and Russell further explained that after the students had recognized the features of insects, Conti provided them with materials, such as construction paper, tape, glue, bottons, crayons, cotton and pins, to build physical models of them in groups, using their drawings as guides. Each group presented its model to the whole class for discussion. The presenters explained the features of their insects, elaborating by talking about such things as their habitats, predators and prey, and answering questions from other students whilst Conti moderated the discussion.

The Combined Role of Mental and Physical Models

In the view of Glynn and Russell (1997), the physical models contributed greatly to the science achievement of Conti's students. They contend that students in general construct mental models when they build physical ones, and this helps them to make sense of their experiences, thereby constructing meaning. Also, the drawing of mental models and building of physical models can help students to understand fundamental scientific concepts. The two are thus complementary and are based on a constructivist view of learning science (Taber & Watts, 1997). In the constructivist view learning is a dynamic process of building, organizing and elaborating knowledge of the natural world (Duit & Glynn, 1995; Britton, Glynn & Yeany, 1991). According to Glynn and Russell, the drawing of mental models is both hands-on and minds-on, and it is therefore inherently constructive in nature and intrinsically motivating to students. In the constructivist view, students never seem to lose interest when drawing what is in their minds, and their drawings help them to consolidate their thoughts about a concept so that the teacher can identify and correct their misconceptions. Glynn and Russell explained that when students' misconceptions have been corrected and their drawings finally validated, they can build physical models from the drawings. To them, the physical models strengthen students' understanding of the concept drawn. Thus, by using evidence from Conti's class, Glynn and Russell have explained that if mental and physical models are combined in the classroom, students' understanding of concepts can be enhanced greatly.

The Content of the SSS Syllabus about Atomic Orbitals

In the SSS chemistry syllabus atomic orbitals are treated in the second year of senior secondary school education under electronic energy levels, which form part of a broader topic namely atomic structure (MOE, 2003). 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 Exclusion Principle (MOE, 2003). The syllabus also requires students to be able to write the detailed electronic configurations of the elements in terms of the 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.

The Content Knowledge of Orbitals in Textbooks

The idea of orbitals is usually introduced in most SSS textbooks under the wave-mechanical concept of the atom after the simpler classical model of the atom has been treated. Whereas the classical model, which came out of the works of Dalton, Rutherford and Bohr, portrays the electrons in an atom as travelling along fixed orbits at fixed distances around the nucleus, the wave-mechanical concept views them as moving in volumes of space known as orbitals around the nucleus (Chang, 1998; Kask & Rawn, 1993; Olmsted & Williams, 1994). Both descriptions of the location and movement of electrons fit into the definition of mental models (Gilbert, 1998), because they are visualized in the mind. Gilbert (1998) defines mental models as models that are visualized in the mind. In accordance with the wave-mechanical model, de Broglie predicted some wave-like characteristics of moving electrons, Davisson and Germer later confirmed the prediction by causing the diffraction of a stream of electrons directed through some crystals (Brown, 1984). According to Brown, diffraction is a characteristic of waves; and de Broglie came out with a mathematical relationship between moving electrons and their associated waves, expressed as

$$\lambda = h/mv$$

where λ is the wavelength of the wave in metres, h is known as Planck constant and has a value of 6.63 x 10^{-34}Js; m is the mass of an electron in kilogrammes; and v is its velocity in metres per second. From the relationship it is observed that

$$\lambda = h/\text{momentum}$$

$$\text{or} \quad \lambda \times \text{momentum} = h$$

Thus, the product of the wavelength of the wave associated with the stream of electrons and the momentum of each of the electrons is constant. It therefore implies that the greater the momentum, the shorter the wavelength and vice versa.

According to Heisenberg, as cited in Chang (1998), Kask and Rawn (1993) and Olmsted and Williams (1994), it is impossible to determine accurately both the position and velocity (or momentum) of a particle as tiny as an electron, and this is known as the Uncertainty Principle. This problem, according to Kask and Rawn, restricted any description of the position and velocity of the electron to a region of probability and probable velocity respectively. According to the wave-mechanical model, the electrons in a given shell of an atom occupy different sub-shells with slightly different energies, and an electron in any given sub-shell occupies a spatial region called an orbital, where the probability of finding the electron is greatest. As indicated in Olmsted and Williams, an orbital is a three-dimensional volume of space around the nucleus of an atom, in which an electron with a given amount of energy is likely to be found. It therefore has a property known as a wave function, which describes the probability of locating an electron within it. Hence, as stated in the Ghana Association of Science Teachers (GAST) chemistry textbook written by Ameyibor and Wiredu (1995), an orbital is a volume of space inside which there is a high probability (usually 95%) of finding a particular electron.

Atomic and Molecular Orbitals

Although each atom has a number of orbitals in which the electrons are found, two atoms involved in covalency have their orbitals containing single electrons overlapping to form a new orbital, in which those electrons then pair up to form a covalent bond (Ameyibor & Wiredu, 1995). The orbitals in a particular atom not involved in covalency are known as atomic orbitals, whereas the new orbital formed from the overlapping orbitals of the two atoms is known as a molecular orbital. Ameyibor and Wiredu gave examples of atomic orbitals as the s-, p-, d- and f-orbitals, and of molecular orbitals as the sigma molecular orbital (or sigma bond) and the pi molecular orbital (or pi bond).

The study that led to this thesis centred on atomic orbitals rather than molecular orbitals. Students were taught the types of atomic orbitals, the number of each type present in a given shell, and the maximum number of electrons that can occupy each orbital. The students also observed the shapes and spatial orientations of the s- and p-orbitals from diagrams, physical models or a combination of both. Moreover, they learnt about the opposite spins of the electron pair in a single orbital. Furthermore, they learnt about the order of increase in energy level of the various atomic orbitals and the order in which these orbitals are occupied by electrons. This led them to write the electronic configurations of elements whose atomic numbers were known to them.

Implications of the Reviewed Literature on this Study

The literature reviewed has shown the abstract nature of the concept of atomic orbitals, which creates a big gap between reading and visualization on the part of students. The need for "bridging conceptions" in the teaching of concepts is also emphasized (Borges & Gilbert, 1999). This suggests that teachers should start the teaching of concepts by using simple models that their students can understand and accept. It implies that the effectiveness of any model meant to be used in teaching needs to be tested. This study is a response to this suggestion because it tested the effectiveness of physical models of atomic orbitals and a combination of models and diagrams against diagrams only, which are the usual teaching aids. It thus attempts to bridge the gap between reading about atomic orbitals and visualization on the part of students.

The literature has also shown that knowledge of the use of models and model-based reasoning is a recent development in education (Borges & Gilbert, 1999; Mayer, 1992; Gilbert, 1994). The implication is that only a few educators are familiar with models and how they can be developed and used in education. This study serves to contribute to the proclamation of models as important tools in science education. It also leads to recommendations to curriculum developers to make innovations in their curriculum, whose development never ends (Oliva, 1992).

CHAPTER 3

METHODOLOGY

Introduction

The purpose of this chapter is to explain how the study was conducted. The chapter gives information on the research design, population and sample for the study, instrument and detailed procedure for data collection.

The Research Design

Being a pretest-posttest group comparison design, a type of quasi-experimental design, it involved three intact groups of students from three schools. The design consisted of a common pretest conducted on all the student groups, various treatments given to the groups, and a common posttest conducted on them. It is illustrated in Table 1.

Table 1

Illustration of the Research Design

Group	Pretest	Treatment	Posttest
1	$O_{x(1)}$	T_1	$O_{y(1)}$
2	$O_{x(2)}$	T_2	$O_{y(2)}$
3	$O_{x(3)}$	T_3	$O_{y(3)}$

The treatment given to a group constituted the independent variable whilst the posttest mean score of a group was the dependent variable. The design made it possible for comparison to be made among various groups of subjects and is therefore described as a "between-subject" design (Keppel, 1991; Rosenthal & Rosnow, 1994).

The rationale for the choice of a quasi-experimental design is that it does not involve randomization of subjects into the various treatment groups. Randomization would disturb the class psychologically, and such disturbance would affect the performance of the subjects in both tests. Randomization would also require student groups to be located in different classrooms, and it might be difficult for enough rooms to be obtained.

Population

The target population for the study comprised all the second-year SSS elective chemistry students in the Cape Coast Municipality in the 2003/2004 academic year. There were eight SSS offering elective chemistry in the Cape Coast Municipality at the time of the study (see Appendix A).

Sample

The sample consisted of students from three schools randomly selected from the population of eight schools. In each school, the students had not been taught atomic orbitals.

One of the selected schools had one stream of second-year science class; another school had two streams whilst the third school had three streams. Faced with time and financial constraints, the researcher selected three intact classes, one from each school. The school with only one science class had that class automatically selected. The classes in each of the other schools were written on pieces of paper, which were then folded such that one could not see what was written on any of them. The folded pieces of paper were mixed up and released onto a table. A colleague was asked to pick one of them, and the class written on the piece of paper picked was selected from the particular school. In one group there were 44 students consisting of 20 boys and 24 girls. In the second group there were 33 students also consisting of 20 boys and 13 girls. In the third school however, there were 46 students, all of them being boys. Appendix B gives information on the ages of students in each group.

The various treatments were assigned to the selected classes from the various schools by means of a ballot. The treatments, designated as "diagrams only", "models only" and "diagrams and models", were written on pieces of paper, which were then folded, mixed up and released onto a table. Pieces of paper bearing the names of the schools were also folded, mixed up and released onto the table. Another colleague was asked to match each piece of paper from those bearing the names of the schools with one from those bearing the treatments. This way, the treatments were assigned to the three schools.

Instruments

The instruments for data collection were made up of a pretest and a posttest on atomic orbitals. For each test, items were developed to test students' understanding of atomic orbitals. Appendix C shows the pretest items and their expected responses whilst Appendix D shows the posttest items and their expected responses.

The pretest items were developed to test students' understanding of atomic orbitals before they were taught the topic. The aim was to find out students' prior ideas about the concept of atomic orbital. Ten objective test items were developed by the researcher and validated by a senior lecturer in the Science and Mathematics Education Department. Thus, the face and content validities of the items were established after the lecturer had made a few modifications.

The posttest items were developed to test students' understanding of atomic orbitals after they had been taught the concept of atomic orbital using the various treatments. These items were 10 objective test items parallel to the pretest items. They were also developed by the researcher and validated by the senior lecturer in chemical education.

Pilot Testing of the Instruments

The items for both tests were tried on a group of 20 second-year SSS students offering chemistry in a school at Nkawkaw. This pilot test was to determine the suitability of the items as well as the reliability of the instruments. Both the pretest and posttest items were found to be reliable with reliability coefficients of 0.76 and 0.75 using the Cronbach alpha formula. These values reflect the internal consistencies of the two tests.

Data Collection Procedure

The pretest was administered to all the student groups in the sample. Students were asked not to write their names, except serial numbers given them on their answer scripts. This was done to assure students of anonymity of their responses to the items. The student groups were then taught the concept of atomic orbital. The researcher personally taught each group, and teaching learning occurred three times in each group. Teaching done on the first occasion was to prepare the groups for the various treatments to be given to the groups on the second and third occasions. Therefore, a common teaching approach, which did not involve the various sets of teaching aids, was used on the first occasion. Each of the first two teaching learning sessions in each group lasted for 80 minutes whilst the third session lasted for 40 minutes giving a total of 200 minutes for each group. After the teaching, all students were given one week to revise their notes on the subject matter taught. The posttest was then administered to the groups. The researcher personally scored students' scripts in both the pretest and posttest.

Subject Matter for the Teaching

The Quantum Theory

When bodies absorb radiations such as heat, their energies increase. When they give out radiations, their energies decrease. The idea of the quantum theory is that the energy change of a body occurs in discrete packets called quanta (singular – quantum) (Ameyibor & Wiredu, 1995; Brown, 1984). A quantum (Q) of energy (in joules) is given by

$$Q = h\upsilon = hc/\lambda \longrightarrow (1)$$

where h is Planck constant of value 6.63×10^{-34} Js. υ is the frequency of the absorbed or emitted radiation (in s^{-1} or Hz), λ is the wavelength of the radiation (in m), and c is the velocity of light (in ms^{-1}). From equation (1), it is found that the total energy change (E) of a body is a whole number multiple of a quantum, which is given by

$$E = nQ = nh\upsilon = nhc/\lambda \longrightarrow (2)$$

where n is a whole number.

Energy Levels of Electrons in an Atom

An atom has several energy levels of its electrons, and the energy of each level is a whole number multiple of a quantum of radiation absorbed or emitted from it (Ameyibor & Wiredu, 1995). (The word "quantum" means "discrete"). Therefore the energy that can be absorbed or given out as radiation from an atom has a value of nhυ or nhc/λ.

Main Energy levels of Electrons

All the electron shells in an atom have associated energy levels of the electrons in them. Electrons in the outer shells have more energy than those in the sinner shells. The difference in energy level between any two shells is nhυ or nhc/λ.

Quantum Numbers of Electrons

The electrons in an atom are at various energy levels and are therefore assigned numbers known as quantum numbers to signify their energy levels (Brown, 1984). All the electrons in the same shell have almost the same amount of energy and are given a number called the principal quantum number (n). This has values 1, 2, 3...from the K-shell (or innermost shell) outwards. Thus, the K-, L-, M- and N-shells have n values of 1, 2, 3 and 4 respectively for their electrons.

In a shell there are sub-shells; any particular sub-shell is made up of orbitals of the same type and shape, which contain the electrons. All electrons in the same sub-shell are given a number called the azimuthal quantum number (1). This is also known as the subsidiary or angular momentum quantum number. For the principal quantum number n, the possible values of l for the electrons present are all the integers from 0 to (n – 1). These l values are given symbols, which are indicated in Table 2. The orbitals in a sub-shell are therefore called by the symbol of azimuthal quantum number for that sub-shell. Thus, there are s-, p-, d- and f-orbitals in

Table 2

Meanings of the Symbols of the Azimúthal Quantum Numbers (l)

l	Symbol	Meaning of Symbol
0	s	Sharp
1	p	Principal
2	d	Diffuse
3	f	Fundamental

the various sub-shells.

In a sub-shell the orbitals have various orientations in space around the nucleus. The electrons in a particular orbital inside a sub-shell are therefore given a third quantum number in accordance with the orientation of that orbital. This is known as the magnetic quantum number (m_l). In a sub-shell with azimuthal quantum number (l), m_l has integral values ranging from –l through 0 up to +l. Since there are a number of sub-shells in a shell, it follows that the possible values of m_l in a particular shell are all the integers from –[l (max)] through 0 up to +[l (max)], where l (max) is the maximum value of l for that shell.

Each orbital can accommodate a maximum of two electrons. Nuclear attraction on these electrons causes them to spin (or turn) on their axes in opposite directions. This therefore brings a fourth quantum number of an electron, which is known as the spin quantum number (m_s). It has a value of –½ for one of the pair of electrons in the orbital, and +½ for the other.

Table 3 gives a summary of all the quantum numbers of electrons in the first two shells of an atom. In the table, the orbital types and their numbers as well as the maximum number of electrons in each shell are also given.

Table 3

Quantum Numbers of Electrons in the First Two Shells of an Atom

Shell	K	L			
n	1	2			
l	0	0	1		
Orbital Type	s	s	p		
m_l	0	0	-1	0	+1
No. of Orbitals	One s	One s	Three p- - - - - - - - - - - - - - - - - - -		
m_s	-½ +½	-½ +½	-½ +½	-½ +½	-½ +½
Max. No. of Electrons	Two in K-shell	Eight in L-shell -			

The Shapes and Orientations of the s- and p-Orbitals

An orbital is a representation of a region of space around the nucleus of an atom in which an electron with a given amount of energy is likely to be found (Olmsted & Williams, 1994). In each electron shell there is one s-orbital, which has a spherical shape. There is no p-orbital in the K-shell. Any other shell of an atom contains three p-orbitals, which are dumbbell-shaped. The s-orbital is illustrated diagrammatically in Fig 1 whilst the three p-orbitals of a shell are illustrated in Fig 2. An orbital is three-dimensional, and the illustrations in Figures 1 and 2 show the x-, y- and z-axes in space, which represent the three dimensions. Any two of the axes make an angle of

90° with each other. Whereas Figure 1 shows the s-orbital at the origin of the three axes, Figure 2 shows the three p-orbitals, whose lobes lie along the axes. As shown in Figure 2, the p-orbital, whose lobes lie on the x-axis, is designated as the p_x-orbital whilst those whose lobes lie along the y- and z-axes, are designated as the p_y- and p_z-orbitals respectively. Thus, any two of the p-orbitals are oriented at right angles to each other. The three p-orbitals of the same shell always exist together and not separately. Figure 3 illustrates a combination of these orbitals as found in an atom. These orbitals also exist together with the s-orbital of the same shell. Figure 4 shows a combination of the s- and the three p-orbitals of the L-shell of an

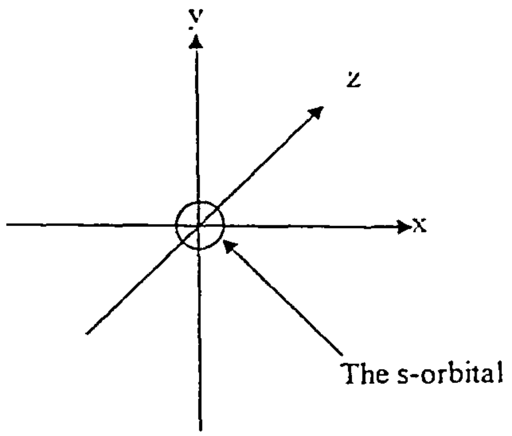


Figure 1: The s-Orbital of an Electron Shell

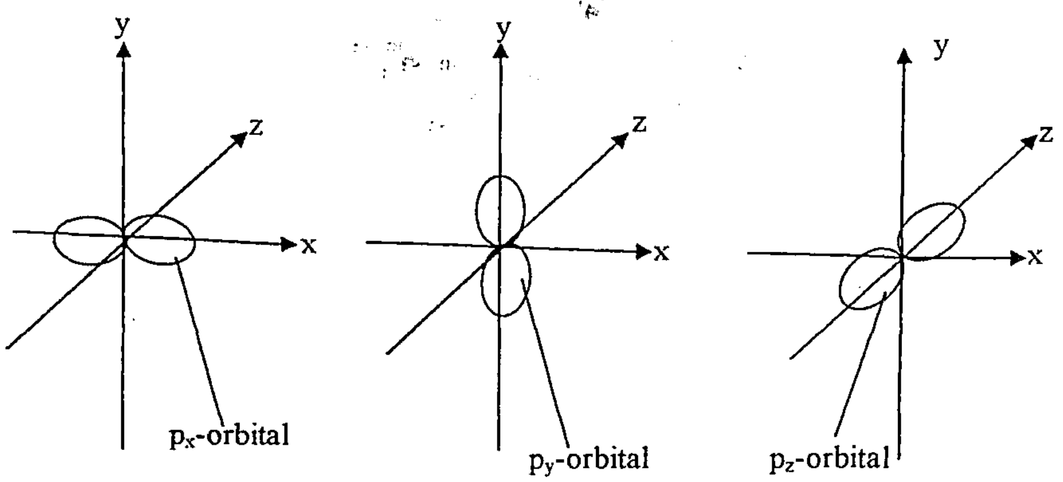


Figure 2: The Three p-Orbitals of an Electron Shell

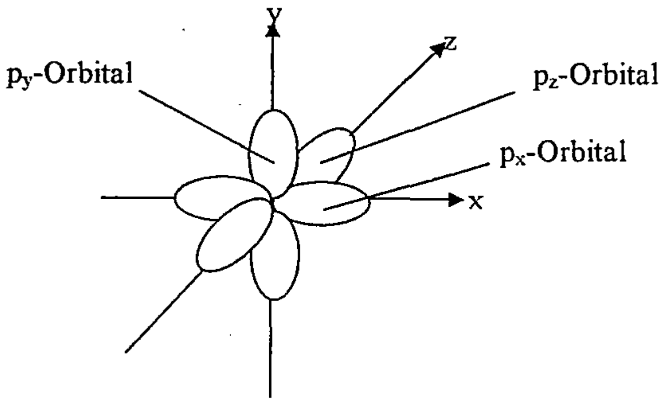


Figure 3: A Combination of the Three p-Orbitals as Normally Found in a Shell of an Atom

atom whilst Appendices E and F show photographs of physical models of the s-and three p-orbitals used in the teaching. A photograph of a combination of the three p-orbitals of a shell is shown in Appendix G. Appendix H shows a photograph of these p-orbitals and the s-orbital combined in the L-shell.

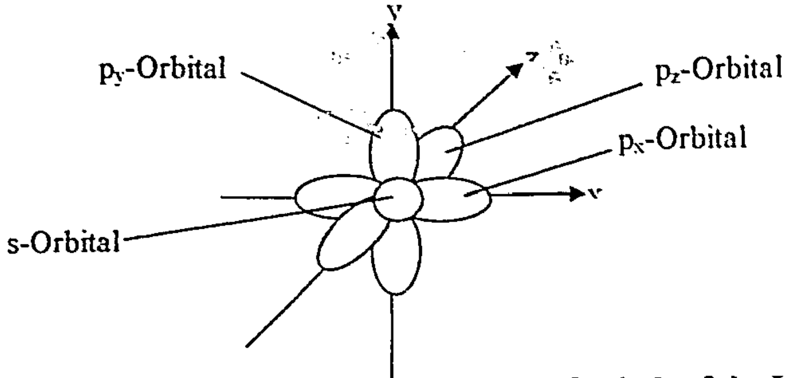


Figure 4: A Combination of the s- and Three p-Orbitals of the L-Shell

Degenerate Orbitals

The three p-orbitals are identical to each other when they occur in the same shell. They are at the same energy level and are therefore known as degenerate orbitals. The only difference among them is in their orientations. All the d-orbitals of the same shell are also at the same energy level and are described as degenerate, and likewise the f-orbitals of the same shell. Degenerate orbitals are orbitals of an atom that are at the same energy level (Brown, 1984).

Pauli Exclusion Principle

Table 3 shows that the two electrons in an orbital have three quantum numbers in common, and these are the principal (n), azimuthal (l) and magnetic (m_l) quantum numbers. This is due to the fact that they are in the same shell, the same sub-shell and the same orbital. The only difference between them is that they have different spins, which are equal and opposite. This difference made Wolfgang Pauli propose a principle known as the Exclusion Principle (Ameyibor & Wiredu, 1995; Brown, 1984; Chang, 1998; Kask & Rawn, 1993; Olmsted & Williams, 1994). According to the principle, no two electrons in the same atom can have exactly the same amount of energy. In other words, no two electrons in the same atom can have all their quantum numbers alike. The principle agrees with the inclusion of the fourth quantum number of an electron, which is the spin quantum number (m_s). It is this quantum number that differentiates between the two electrons in the same orbital.

The Aufbau Principle

"Aufbau" is the German for "building up". The principle says that electrons always occupy the lowest empty energy level (Ameyibor & Wiredu, 1995). In other words, for any atom, the electronic configuration with the lowest energy (ground state) is obtained by the assignment of the electrons in pairs to the orbitals of lowest energy in sequence (Kneen, Rogers & Simpson, 1984). This means that as protons increase in number by one in the nucleus to build up the elements, electrons similarly increase in the orbitals, starting from the orbital with the lowest energy.

General Order for Filling the Orbitals with Electrons

The arrows in Fig 5 show the order in which the energy levels of the orbitals increase, starting from the 1s orbital at the top and moving downwards. Therefore, in accordance with the Aufbau Principle, electrons

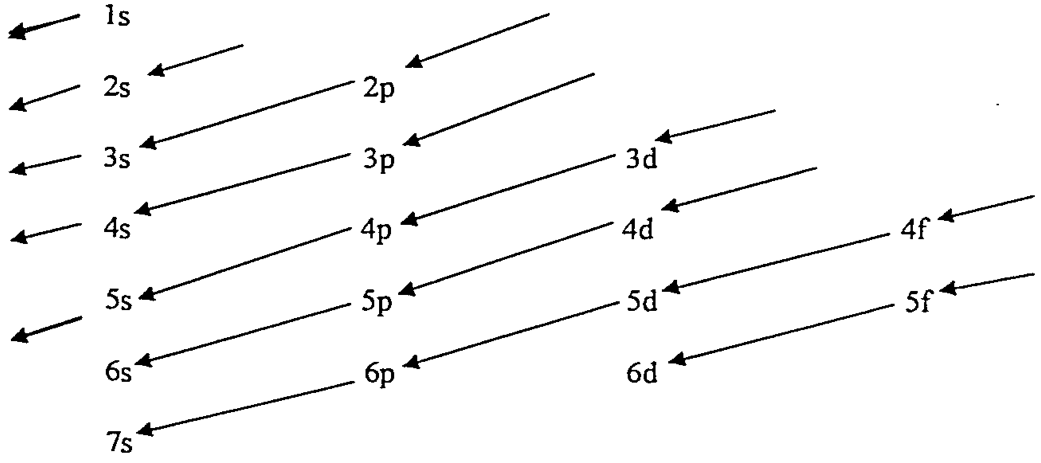


Figure 5: General Order for Filling the Orbitals with Electrons

occupy the orbitals in the same order.

Representation of an Orbital

An orbital is represented by the principal quantum number (n) followed by the type of orbital. Table 4 shows the orbitals in the first three shells, which are represented this way.

Hund's Rule of Maximum Multiplicity

Hund suggested that all the degenerate energy levels of an atom must be occupied by single electrons before any pairing up of electrons with opposite spins can occur in the same orbital. This is known as the Rule of Maximum Multiplicity (Kneen, Rogers & Simpson, 1984). This is due to the fact that electrons repel each other, and their pairing up therefore requires higher energy input. Appendix I shows a photograph of two discs used in the demonstration of the opposite spins of the electron pair in an orbital.

Table 4

Orbitals in the First Three Shells

Shell	n	Orbitals Present
K	1	s
L	2	s, p
M	3	s, p, d

Ground-State Electronic Configurations of some Elements

Ground-state electronic configurations are written by the application of the Aufbau Principle and Hund's Rule of Maximum Multiplicity. The following are examples for carbon, nitrogen and oxygen atoms.

$_6C$: $1s^2$ $2s^2$ $2p_x^1$ $2p_y^1$

$_7N$: $1s^2$ $2s^2$ $2p_x^1$ $2p_y^1$ $2p_z^1$

$_8O$: $1s^2$ $2s^2$ $2p_x^2$ $2p_y^1$ $2p_z^1$

Lesson Plans for Teaching-Learning

In this section the lesson plans used for the teaching-learning activities in all the student groups are presented. Each group was met three times, and the material taught was treated under three different topics namely "Electronic Energy Levels and Atomic Orbitals", "The Shapes and Orientations of the s- and p-Orbitals, Electron Spin and the Aufbau Principle" and "Electronic Configurations of Elements".

First Lesson Plan: All Groups

Topic: Electronic Energy Levels and Atomic Orbitals

Duration: 80minutes

Assumed Previous Knowledge: Students can define energy and state some forms of it. They can also define potential energy. Moreover, they can state the three ways by which heat energy is transferred.

Objectives: By the end of the lesson students must be able to:

(i) Use the quantum theory to explain that the total energy change of a body is in definite bits known as quanta;

(ii) use the idea of quantum numbers to explain that electrons in an atom have several energy levels, and they are found in orbitals;

(iii) state the azimuthal and magnetic quantum numbers possible for electrons with given principal quantum numbers.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give responses such as the following:
1. What is energy?	1. Energy is the capacity to do work.
2. Mention some forms of energy.	2. Some energy forms are kinetic, potential, elastic and heat.
3. What is meant by potential energy of a body?	3. The potential energy of a body is its energy as a result of its distance above a reference level such as the ground.
4. State three ways by which heat energy may be transmitted.	4. Heat may be transmitted by conduction, convection or radiation.
Development:	
The Quantum Theory (13min): Teacher introduces and explains the quantum theory to students as shown in the subject matter.	Students take down notes.
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. From the quantum theory, what is the relationship between the value of a quantum of a radiation and the	1. A quantum (Q) is directly proportional to the frequency (υ) but

Teacher's Activities	Students' Activities
frequency or the wavelength?	Inversely proportional to the wavelength (λ).
2.Explain your response to Question 1 above.	2. In the equation $Q = h\upsilon = hc/\lambda$, h and c are constant. Therefore hc is also constant. Hence, mathematically, $Q \,\alpha\, \upsilon$ and $Q \,\alpha\, 1/\lambda$
3. What is the relationship between the total energy change of a body and the value of a quantum of radiation absorbed or emitted from it?	3. The total energy change of a body is a whole number multiple of the value of a quantum of radiation absorbed or emitted from it.
Energy Levels of Atoms (5min):	
Teacher introduces to students the concept of electronic energy levels in an atom as shown in the subject matter.	Students listen and take down notes.
Main Energy Levels of Electrons	
(18 min): Teacher asks students the following questions: 1. When you are moving to the top floor of a five-storey building from the	1. Students are expected to give the following responses: 2. A person climbing to the top floor of a five-storey building enters the floors in the order: ground floor,

Teacher's Activities	Students' Activities
ground, in which order do you reach the floors?	first floor, second floor, third floor, fourth floor, fifth floor.
2. What form of energy do you gain by climbing to the floors?	2. The person climbing gains potential energy.
3. What is the order of increase of this form of energy on the floors?	3. The potential energy increases in the order in which the floors are reached.
4 What happens to the potential energy of an object as it moves higher above the ground?	4. The potential energy of an object increases as it moves higher above the ground.
5. What is the expected order of increase of energy level of the electron shells?	5. The energy levels of the electron shells are expected to increase in the order K, L, M, N,...
6. Why is the energy level of the shells expected to increase in the order stated in response to Question 5?	6. This is due to the fact that the shells get farther away from the nucleus in the order K, L, M, N and also, the electrons occupy them in that order.
Teacher explains to students the main energy levels of electrons in an atom.	
Quantum Numbers of Electrons	
(34 min): Teacher asks students the following questions:	Students are expected to give responses such as the following:

Teacher's Activities	Students' Activities
1. In a school, how are students grouped for learning?	1.In a school, students are grouped according to classes. In a class there are rows, which are sub-groups. In a row there are various positions occupied by students.
2. What factors are considered in placing students in particular classes in the SSS?	2. Students are placed in classes in the SSS according to their experiences and academic programmes.
Teacher relates the classes in which students are grouped to the energy levels of the shells and associated principal quantum numbers (n), explaining the principal quantum number of an electron.	
Teacher asks students the following questions:	Students are expected to give the following responses:
1. What are the first four shells of an atom?	1. The first four shells of an atom are the K-, L-, M- and N-shells.
2.What is the order of increase of energy level in these shells?	2. The energy level increases in the order $K < L < M < N$.
3. What are the values of n in the shells?	3. The K-, L-, M- and N-shells have n values of 1, 2, 3 and 4 respectively.
Teacher explains the azimuthal quantum number (l) as shown in the subject mater and relates the rows in a class to the	Students listen and take down notes.

Teacher's Activities	Students' Activities
energy levels of the sub-shells and associated azimuthal quantum numbers (l). He explains that the azimuthal quantum numbers 0, 1, 2, and 3 have the symbols s, p, d, and f respectively representing them. Teacher also explains that these symbols are used as names for the orbital types in the sub-shells.	
Teacher asks students the following questions:	The following responses are expected from students:
1. How many l values can be assigned to electrons in each of the first four shells of an atom?	1. The numbers of l values for electrons in the shells are as follows: K-shell – one L-shell – two M-shell – three N-shell – four
2. What are the l values in these shells?	2. The values are as follows: K-shell – 0 L-shell – 0, 1 M-shell – 0, 1, 2 N-shell – 0, 1, 2, 3
3. What orbital types can be found in the first four shells of an atom?	3. The orbital types in the shells are: K-shell – s

Teacher's Activities	Students' Activities
	L-shell – s, p M-shell – s, p, d N-shell – s, p, d, f
Teacher explains the magnetic quantum number (m_l) of an electron as the quantum number due to the orientation of the orbital containing the electron. Teacher also states the rules for assigning m_l values to orbitals in a sub-shell or a shell (The details are in the subject matter). Teacher asks students the following questions:	The following responses are expected from students:
1. What are the possible values of m_l when l has values 0, 1 and 2?	1. When l is 0, m_l can only be equal to 0. When l is 1, m_l can be –1, 0 or +1. When l is 2, m_l can be – 2, –1, 0, +1 or +2.
2. How many orbitals of the type s, p, d or f can occur in the same shell?	2. In the same shell there can be one s-, three p-, five d- or seven f-orbitals.
Teacher explains the spin quantum number (m_s) of an electron as the quantum number due to the direction of rotation (or spin) of the electron in an orbital. Teacher also states the possible m_s	

Teacher's Activities	Students' Activities
values of electrons in an orbital as + ½ and – ½.	
<u>Closure (5min)</u>:	
Teacher asks students the following questions:	Responses such as the following are expected from students:
1. What are the maximum numbers of electrons in the s-, p-, d- and f-orbitals in a shell?	1. In a shell, the maximum numbers of electrons in the orbitals are as follows: There can be two in the s-orbital, six in the p-orbitals, ten in the d-orbitals, and fourteen in the f-orbitals.
2. What is the relationship between the number of orbitals of each type and the maximum number of electrons in those orbitals?	2. The maximum number of electrons in orbitals of each type is twice the number of those orbitals.
3. Why does this relationship occur?	3. This relationship occurs because each orbital can accommodate a maximum of two electrons. Thus, the ratio of the number of orbitals to the maximum number of electrons is 1 : 2.

Second Lesson Plan for "Diagrams Only" Group

Topic: The Shapes and Orientations of the s- and p-Orbitals, Electron Spin and the Aufbau Principle

Duration: 80min

Assumed Previous Knowledge: Students know that there are various types of atomic orbitals namely the s-, p-, d- and f-orbitals, and that the electrons in them have quantum numbers signifying their energy levels. Moreover, they know that in a shell, there can be one s-, three p-, five d- and seven f-orbitals.

Objectives: By the end of the lesson students should be able to:

(i) draw and explain the shapes and orientations of the s- and p- orbitals;

(ii) state Pauli Exclusion Principle;

(iii) state the order in which electrons fill the orbitals in the first three shells.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. State the various types of atomic orbitals.	1. The atomic orbital types are s, p, d and f.
2. Which types are present in the K- and L-shells?	2. The type present in the K-shell is the s. In the L-shell there are s and p types
3. What is the azimuthal quantum number (l) of the electrons in the p-orbitals?	3. The azimuthal quantum number (l) of the electrons in the p-orbitals is 1.
4. How many s-orbitals and p-orbitals can there be in a shell?	4. In a shell there can be one s- and three p- orbitals.

Teacher's Activities	Students' Activities
Development: The Shapes and Orientations of the s- and p-Orbitals (20min): Teacher guides students to define an orbital by observing a poster of the single s- and three p-orbitals.	Students observe the diagrams of orbitals on the poster and try to define an orbital, guided by teacher.
Teacher asks students to respond to the following:	The following responses are expected from students:
1. Describe the shapes of the s- and p-orbitals as observed from the poster.	1.The s-orbital is spherical in shape whilst the p-orbital has a dumbbell shape.
2. What is the angle between the directions of orientation of the p_x- and p_y-orbitals, the p_x- and p_z-orbitals, and the p_y- and p_z-orbitals?	2. The directions of orientation of any two of the p-orbitals make an angle of 90°. Thus, any two of those orbitals are oriented perpendicularly to each other.
Teacher displays a poster of a combination of the p-orbitals of the same shell, and a combination of the s- and the three p-orbitals of the L-shell before the class.	Students attempt to draw these orbitals to show their participation in the lesson.
Teacher asks students to respond to the following:	The following responses are expected from students:
1. Observe the diagram and describe the relationship between the	1. The directions of orientation of the three p-orbitals of a shell are

Teacher's Activities	Students' Activities
directions of orientation of the three p-orbitals of a shell.	perpendicular to one another.
2. How would you compare the energy levels of the s-orbital and the three p-orbitals of the same shell?	2. The p-orbitals are at the same energy level. However, their energy level is higher than that of the s-orbital.
3. Explain why these comparisons hold for the orbitals in Question two.	3. The poster shows that all the p-orbitals are similar in shape and size and have the same reach from the centre. However, they are farther from the centre than the s-orbital.
Teacher explains degenerate orbitals to students and cites examples as the three p-orbitals of the same shell, the five d-orbitals of the same shell, or the seven f-orbitals of the same shell.	Students listen and take down notes.
<u>Pauli Exclusion Principle (25min)</u>:	
Teacher asks students the following questions based on their previous knowledge:	The following responses are expected from students:
1. What are the total numbers of orbitals in the K-, L- and M-shells of an atom?	1. The numbers of orbitals in the shells are as follows:

Teacher's Activities	Students' Activities
	K-shell: Only one s-orbital = 1 orbital L-shell: One s + Three p = 4 orbitals M-shell: One s + Three p + Five d = 9 orbitals
2. What are the maximum numbers of electrons possible in these shells?	2. The maximum numbers of electrons are as follows: K-shell: $n = 1$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 1^2 = 2$ L-shell: $n = 2$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 2^2 = 8$ M-shell: $n = 3$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 3^2 = 18$
3. What is the relationship between the total number of orbitals in a shell and the maximum number of electrons possible in it?	3. The maximum number of electrons possible in a shell is observed to be twice the number of orbitals in it.
4. Why does this relationship exist?	4. This relationship exists because each orbital can be occupied by a maximum of two electrons.

Teacher's Activities	Students' Activities
Teacher explains the Pauli Exclusion Principle and how it originated as a result of the different spins of the pair of electrons in the same orbital. Teacher displays before students a poster of the sign [↑↓] and explains how the arrow directions represent the directions of spin of the electron pair in an orbital.	Students listen to teacher, observe the poster and take down notes.
The Filling of Orbitals in the First Three Shells with Electrons (25 min):Teacher asks students the following Questions based on their previous knowledge:	The following responses are expected from students:
1. What is the order of increase of energy level in the K-, L- and M-shells of an atom?	1. The energy levels of the shells increase in the order K, L M.
2. In what order are they filled by electrons?	2. Electrons fill them in the same order.
3. What rule is followed when electrons are filling the shells?	3. The rule is that lower-energy shells are filled by electrons before higher-energy shells are filled. This is the situation in a stable atom, which is said to be in

Teachers' Activities	Students' Activities
	its ground state.
Teacher explains the Aufbau Principle to students and shows how it governs the order in which electrons fill the orbitals. Teacher explains to students the representation of an orbital by the use of the principal quantum number (n) followed by the orbital type.	Students listen to teacher and take down notes.
<u>Closure (5min)</u>:	
Teacher asks students to respond to the following:	The following responses are expected from students:
1. Give the representations of all the orbitals in the K-, L- and M- shells.	1. In the K-shell, $n = 1$ $\therefore$ Orbital Present = 1s In the L-shell, $n = 2$ $\therefore$ Orbitals Present = 2s, 2p In the M-shell, $n = 3$ $\therefore$ Orbitals Present = 3s, 3p, 3d
2. Arrange all the orbitals in the K-, L- and M- shells in the order of increasing energy level.	2. The energy levels of the orbitals increase in the order $1s < 2s < 2p < 3s < 3p < 3d$.
3. In what order are they expected to be filled by electrons?	3. They are expected to be filled by electrons in the same order.

Teachers' Activities	Students' Activities.
4. Why are the orbitals in the K-, L- and M-shells expected to be filled in the order stated in response to Question 3?	4. The reason is that in accordance with the Aufbau Principle, some electrons must occupy lower-energy levels before the rest occupy higher-energy levels.

Second Lesson Plan for "Models Only" Group

Topic: The Shapes and Orientations of the s- and p-Orbitals, Electron Spin and the Aufbau Principle

Duration: 80 minutes.

Assumed Previous Knowledge: Students know that there are various types of atomic orbitals namely the s-, p-, d- and f-orbitals, and that the electrons in them have quantum numbers signifying their energy levels. They also know the orbital types in each shell. Moreover, they know that in a shell, there can be one s-, three p-, five d- and seven f-orbitals.

Objectives: By the end of the lesson students should be able to:

(i) draw and explain the shapes and orientations of the s- and p- orbitals;

(ii) state Pauli Exclusion Principle;

(iii) state the order in which electrons fill the orbitals in the first three shells of an atom.

Teacher's Activities	Students' Activities
<u>Introduction (5min)</u>:	
Teacher asks students to respond to the following:	Students are expected to give the following responses:

Teacher's Activities	Students' Activities
1. State the various types of atomic orbitals.	1. The atomic orbital types are s, p,d and f.
2. Which types are present in the K- and L-shells?	2.The type present in the K-shell is the s. In the L-shell are the s and p types.
3. What is the azimuthal quantum number (l) of the electrons in the p-orbitals?	3. The azimuthal quantum number of the electrons in the p-orbitals is 1.
4. How many s-orbitals and p-orbitals can there be in a shell?	4. In a shell there can be one s- and three p-orbitals.

Development:

The Shapes and Orientations of the s- and p-Orbitals (20min):

Teacher guides students to define an orbital by observing physical models of the single s-orbital and three p-orbitals. Teacher asks students to respond to the following:	Students observe the models of orbitals and try to define an orbital, guided by teacher The following responses are expected from students:
1. Describe the shapes of the s- and p-orbitals as observed from the physical models.	1. The s-orbital is spherical in shape whilst the p-orbital has a dumbbell shape.
2. Remove the model of the p_z-orbital and observe the orientations of the	2. (A student removes the model of the p_z-orbital, and the whole

Teacher's Activities	Students' Activities
p_x- and p_y-orbitals. What is the angle between the directions of orientation of these two orbitals?	class observes the orientations of the p_x- and p_y- orbitals.) The angle between the directions of orientation of the p_x- and p_y-orbitals is 90°.
3 Replace the model of the p_z-orbital. By removing the p_y-orbital model, observe the p_x- and p_z- orbital models and state the angle between their directions of orientation.	3. (A student replaces the model of the p_z and removes the p_y-orbital model as the class observes). The angle between the directionsof orientation of the p_x- and p_z-orbitals is also 90°.
4. Replace the p_y and remove the p_x. Observe and state the angle between the directions of orientation of the p_y-nand p_z-orbitals.	4. (A student replaces the p_y and removes the p_x as the class observes). The angle between the directions of orientation of the p_y- and p_z- orbitals is 90°.
5. Arrange the lobes of all the p-orbitals together on three of the metal rods that are soldered together. Describe the relationship among the directions of orientation of the three p-orbitals of a shell, using the combined	5. The directions of orientation of the three p-orbitals of a shell are perpendicular to one another.

Teacher's Activities	Students' Activities
arrangement of the lobes as a guide	
6. Arrange the lobes of all the p-orbitals on the metal rods around the s-orbital. How would you compare the energy levels of the s-orbital and the three p-orbitals of the same shell?	6. The p-orbitals are at the same energy level. However, their energy level is higher than that of the s-orbital.
7. Why do the energy levels of the orbitals in Question 6 compare this way?	7. The arrangement of all the orbitals shows that the p-orbitals are similar in shape and size and have the same reach from the centre. However, they extend farther from the centre than the s-orbital.
Teacher explains degenerate orbitals to students and cites examples as the three p-orbitals, the five d-orbitals, or the seven f-orbitals of the same shell.	
Pauli Exclusion Principle (25min): Teacher asks students the following questions based on their previous knowledge.	The following responses are expected from students:

Teacher's Activities	Students' Activities
1. What are the total numbers of orbitals in the K-, L- and M-shells of an atom?	1. The numbers of orbitals in the shells are as follows: K-shell: Only one s-orbital = 1 orbital L-shell: One s + Three p = 4 orbitals M-shell: One s + Three p + Five d = 9 orbitals
2. What are the maximum numbers of electrons possible in the shells in Question 1 above?	2. The maximum numbers of electrons are as follows: K-shell: $n = 1$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 1^2$ $= 2$ L-shell: $n = 2$ $\therefore$ Maximum number $= 2 \times n^2$ $= 2 \times 2^2$ $\therefore$ Maximum number $= 8$ M-shell: $n = 3$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 3^2$ $= 1$

Teacher's Activities	Students' Activities
3. What is the relationship between the total number of orbitals in a shell and the maximum number of electrons possible in it?	3. The maximum number of electrons possible in a shell is observed to be twice the number of orbitals in it.
4. Why does this relationship exist?	4. This relationship exists because each orbital can be occupied by a maximum of two electrons.
Teacher explains the Pauli Exclusion Principle and how it originated as a result of the different spins of the pair of electrons in the same orbital. Teacher mounts on the metal rods before the class two wooden discs in contact for demonstrating the opposite spins of the electron pair in an orbital. Teacher turns one of the discs around its metal rod, and it lets the other disc turn at the same speed in the opposite direction. Teacher uses this to explain to students the equal and opposite spins of the electron pair in an orbital.	Students listen to teacher, observe the demonstration of opposite spins and take down notes.

Teacher's Activities	Students' Activities
The Filling of Orbitals in the First Three Shells with Electrons (25min):	
Teacher asks students the following questions based on their previous knowledge.	The following responses are expected from students:
1. What is the order of increase of energy level in the K-, L- and M - shells of an atom?	1. The energy levels of the shells increase in the order K, L, M.
2. In what order are they filled by electrons?	2. Electrons fill them in the same order.
3. What rule is followed when electrons are filing the shells?	3. The rule is that lower-energy shells are filled before higher-energy shells are filled. This is the situation in a stable atom, which is said to be in its ground state.
Teacher explains the Aufbau Principle to students and shows how it governs the order in which electrons fill the orbitals. Teacher explains to students the representation of an orbital by the use of the principal quantum number (n)	Students listen to teacher and take down notes.

Teacher's Activities	Students' Activities
followed by the orbital type.	
Closure (5min):	
Teacher asks students to respond to the following:	The following responses are expected from students:
1. Give the representations of all the orbitals in the K-, L- and M-shells.	1. In the K-shell, n = 1 ∴ Orbital Present = 1s In the L- shell, n = 2 ∴ Orbitals Present = 2s, 2p, In the L- shell, n = 3 ∴ Orbitals Present = 3s, 3p, 3d
2. Arrange all the orbitals in the K-, L- and M-shells in the order of increasing energy level.	2. The energy levels of the orbitals increase in the order 1s < 2s < 2p < 3s < 3p < 3d.
3. In what order are the orbitals in Question 2 expected to be filled with electrons?	3. They are expected to be filled with electrons in the same order.
4. Why are the orbitals in the K-, L- and M-shells expected to be filled in the order stated in response to Question 3?	4. The reason is that in accordance with the Aufbau Principle, some electrons must occupy lower-energy levels before the rest occupy higher- energy levels.

Second Lesson Plan for "Diagrams and Models" Group

Topic: The Shapes and Orientations of the s-and p-Orbitals, Electron Spin and the Aufbau Principle

Duration: 80 minutes.

Assumed Previous Knowledge: Students know that there are various types of atomic orbitals namely the s-, p-, d- and f-orbitals, and that the electrons in them have quantum numbers signifying their energy levels. They also know the orbital types in each shell. Moreover, they know that in a shell, there can be one s-, three p-, five d- and seven f-orbitals.

Objectives: By the end of the lesson students should be able to:

(i) draw and explain the shapes and orientations of the s- and p-orbitals;

(ii) state Pauli Exlusion Principle;

(iii) state the order in which electrons fill the orbitals in the first three shells.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. State the various types of atomic orbitals.	1. The atomic orbital types are s, p, d and f.
2. Which types are present in the K- and L-shells?	2. The type present in the K-shell is the s. In the L-shell there are the s and p types.
3. What is the azimuthal quantum	3. The azimuthal quantum number

Teacher's Activities	Students' Activities
number (l) of the electrons in the p- orbitals?	(l) of the electrons in the p-orbitals is 1.
4. How many s-orbitals and p-orbitals can there be in a shell?	4. In a shell there can be one s- and three p-orbitals.

Development:

The Shapes and Orientations of the s- and p-Orbitals (20min): Teacher guides students to define an orbital by observing a poster and physical models of the single s- and three p-orbitals. Teacher asks students to respond to the following:	Students observe the diagrams and physical models of orbitals and try to define an orbital, guided by teacher. The following responses are expected from students:
1. Observe the poster and the physical models carefully and describe the shapes of the s- and p-orbitals from your observation.	1. The s-orbital is spherical in shape whilst the p-orbital has a dumbbell shape.
2. Remove the model of the p_z-orbital and observe the orientations of the p_x- and p_y-orbitals. Also observe the orientations of these two orbitals from the poster. From your observation of the poster and models, state the angle between	2. (A student removes the model of the p_z-orbital, and the whole class observes the orientations of the p_x- and p_y-orbitals from both the poster and models). The angle between the directions of orientation of the p_x- and p_y-

Teacher's Activities	Students' Activities
the directions of orientation of the p_x- and p_y- orbitals.	orbitals is 90°.
3. Replace the model of the p_z-orbital. Remove the model of the p_y- orbital and observe the p_x- and p_z-orbitals from both the models and the poster. State the angle between the directions of orientation of the p_x- and p_z-orbitals.	3. (A student replaces the model of the p_z and removes the p_y-orbital model as the class observes the models and the poster.) The angle between the directions of orientation of the p_x- and p_z-orbitals is also 90°.
4. Replace the p_y and remove the p_x-orbital model. Observe the models and the poster and state the angle between the directions of orientation of the p_y- and p_z-orbitals.	4. (A student replaces the p_y and removes the p_x-orbital model as the class observes the models and the poster). The angle between the directions of orientation of the p_y- and p_z- orbitals is 90°.
Teacher displays a poster of a combination of all the p-orbitals of the same shell, and a combination of the s-orbital and the three p-orbitals of the L-shell before the class. Teacher asks students to respond to the following:	The following responses are expected from students:

Teacher's Activities	Students' Activities
1. Arrange the lobes of all the p-orbitals together on three of the metal rods that are soldered together. Observe the arrangement and the diagram on the poster and describe the relationship between the directions of orientation of the three p-orbitals of a shell.	1. (A student does the arrangement as the class observes). The directions of orientation of the three p-orbitals are perpendicular to one another.
2. Arrange the lobes of all the p-orbitals on the metal rods around the s-orbital. Observe the arrangement and the diagram on the poster. How would you compare the energy levels of the s-orbital and the three p-orbitals of the same shell?	2. (A student does the arrangement as the class observes). The p-orbitals are at the same energy level. However, their energy level is higher than that of the s-orbital.
3. Why do the energy levels of the orbitals in Question 2 compare this way?	3.The poster and the arrangement of all the orbital models show that the p-orbitals are similar in shape and size and have the same reach from the centre. However, they are bigger and extend farther from the centre than the s-orbital.

Teacher's Activities	Students' Activities
Teacher explains degenerate orbitals to students and cites examples as the three p-orbitals, the five d-orbitals, and the seven f-orbitals of the same shell.	
Pauli Exclusion Principle (25min):	
Teacher asks students the following questions based on their previous knowledge.	The following responses are expected from students:
1. What are the total numbers of orbitals in the K-, L- and M-shells of an atom?	1. The numbers of orbitals in the shells are as follows: K-shell: Only one s-orbital = 1 orbital L-shell: One s + Three p = 4 orbitals M-shell: One s + Three p + Five d = 9 orbitals.
2. What are the maximum numbers of electrons possible in these shells?	2. The maximum numbers of electrons are as follows: K-shell: $n = 1$ $\therefore$ Maximum number $= 2n^2$ $= 2 \times 1^2$

Teacher's Activities	Students' Activities
	$\therefore$ Max number in K = 2 L-shell: n = 2 $\therefore$ Maximum number $= 2n^2$ $= 2 \times 2^2$ $= 8$ M-shell: n = 3 $\therefore$ Maximum number $= 2n^2$ $= 2 \times 3^2$ $= 18$
3. What is the relationship between the total number of orbitals in a shell and the maximum number of electrons possible in it?	3. The maximum number of electrons possible in a shell is observed to be twice the number of orbitals in it.
4. Why does this relationship exist?	4. This relationship exists because each orbital can be occupied by a maximum of two electrons.
Teacher explains the Pauli Exclusion Principle and how it originated as a result of the different spins of the pair of electrons in the same orbital.	Students listen to teacher, observe the poster and the demonstration of opposite spins and take down notes.
Teacher displays before students a poster of the sign [↑↓] and mounts on the metal rods two wooden discs in contact for demonstrating the opposite	

Teacher's Activities	Students' Activities
spins of the electron pair in an orbital. Teacher turns one of the discs around its metal rod, and it causes the other disc to turn at the same speed in the opposite direction. Teacher uses this and the sign [↑↓] to explain to students the equal and opposite spins of the electron pair in an orbital.	
The Filling of Orbitals in the First Three Shells with Electrons (25min):	
Teacher asks students the following questions based on their previous knowledge.	The following responses are expected from students:
1. What is the order of increase of energy level in the K-, L- and M-shells of an atom?	1. The energy levels of the shells increase in the order K, L, M.
2. In what order are they filled by electrons?	2. Electrons fill them in the same order.
3. What rule is followed when electrons are filing the shells?	3. The rule is that lower-energy shells are filled before higher-energy shells. This is the situation in a stable atom, which is said to be in its ground state.
Teacher explains the Aufbau-Principle to students and shows how it governs	Students listen to teacher and take down notes.

Teacher's Activities	Students' Activities
the order in which electrons fill the orbitals. Teacher explains to students the representation of an orbital by the use of the principal quantum number (n) followed by the symbol for the orbital type.	

Closure (5min):

Teacher asks students to respond to the following:	The following responses are expected from students:
1. Give the representations of all the orbitals in the K-, L- and M-shells.	1. In the K-shell, n = 1 ∴ Orbital Present = 1s In the L-shell, n = 2 ∴ Orbitals Present = 2s, 2p, In the M-shell, n = 3 ∴ Orbitals Present = 3s, 3p, 3d
2. Arrange all the orbitals in the K-, L- and M-shells in the order of increasing energy level.	2. The energy levels of the orbitals increase in the order 1s, 2s, 2p, 3s, 3p, 3d.
3. In what order are they expected to be filled with electrons?	3. They are expected to be filled with electrons in the same order.
4. Why are the orbitals in the K-, L-	4. The reason is that in accordance with the Aufbau Principle, some electrons

Teacher's Activities	Students' Activities
and M- shells expected to be filled in the order stated in response to Question 3?	must occupy lower-energy levels before the rest occupy higher-energy levels.

Third Lesson Plan for "Diagrams Only" Group

Topic: Electronic Configurations of Elements

Duration: 40minutes

Assumed Previous Knowledge: Students know that according to the Aufbau Principle, some electrons occupy lower-energy levels in an atom before others occupy higher-energy levels. They also know the representation of an orbital by the use of the principal quantum number and the type of orbital. Moreover, they know that all orbitals of the same type in a given shell are degenerate.

Objectives: By the end of the lesson students should be able to:

(i) apply Hund's Rule of Maximum Multiplicity to state the order in which degenerate orbitals are occupied by electrons;

(iii) apply Hund's Rule of Maximum Multiplicity, the Aufbau Principle and the order for filling all orbitals with electrons to state the electronic configurations of elements whose atomic numbers are known.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. State the Aufbau Principle.	1. Electrons always enter the lowest

Teacher's Activities	Students' Activities
	empty energy level in an atom.
2. How would you represent the orbitals in the K-, L-, and M-shells of an atom?	2. The orbitals in the shells are as follows: K-shell: 1s orbital L-shell: 2s orbital 2p orbitals M-shell: 3s orbital 3p orbitals 3d orbitals
3. What are the degenerate orbitals in the L-shell?	3. The degenerate orbitals in the L-shell are the $2p_x$, $2p_y$ and $2p_z$ orbitals.

<u>Development</u>:

<u>Hund's Rule of Maximum Multiplicity (20min)</u>: Teacher explains to students Hund's Rule of Maximum Multiplicity. Teacher displays before the class posters of the three p-orbitals and the sign ($\upharpoonleft\downharpoonright$) and asks students to respond to the following:	Students listen to teacher and observe the posters. Responses such as the following are expected from students:
1. What difference do you observe among the three p-orbitals on the poster?	1. The three p-orbitals have different orientations.
2. Does the energy level of a p-orbital depend upon its orientation?	2. The energy level of a p-orbital does not depend upon its

Teacher's Activities	Students' Activities
	orientation.
3. What is the relationship among the three p-orbitals of the same shell in terms of energy level?	3. All the three p-orbitals of the same shell are at the same energy level.
4. Observe the sign [↑↓] and state the relationship between the spins of the electron pair in an orbital.	4. The spins of the electron pair in an orbital are equal and opposite.
5. If the three p-orbitals of the same shell are empty and are to be filled with six electrons, in what manner will they be filled?	5. All the three p-orbitals will first be occupied by single electrons before the rest of the electrons are distributed over them to pair up with those that have already occupied them.
6. What is the relationship among the spins of the first set of single electrons that occupy these orbitals?	6. The first set of single electrons in the orbitals spin in the same direction.
7. What is the relationship between the spins of the electron pair in the same orbital?	7. The spins of the electron pair in the same orbital are equal and opposite.
8. Write the detailed electronic configurations of nitrogen, oxygen, sodium and chlorine with atomic numbers 7, 8, 11 and 17 respectively.	8. The electronic configurations are as follows: $_7N$: $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^1$ $_8O$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1\ 2p_z^1$ $_{11}Na$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^1$

Teacher's Activities	Students' Activities
	$_{17}\text{Cl}:\ 1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^1$
Teacher explains to students that just as Hund's Rule of Maximum Multiplicity applies to the filling of all the three p-orbitals of a shell, it also applies to the filling of all the five d- or seven f-orbitals of a shell with electrons.	Students listen to teacher and take down notes.
The Order for Filling All the Orbitals with Electrons (5min): Teacher summarizes the order for filling all the orbitals with electrons by drawing the chart of Fig 5 on the chalkboard.	Students listen, observe and draw the chart presented by teacher.
Closure (10min): Teacher asks students to respond to the following: 1. From the chart drawn on the board, in what order do the energy levels of all the orbitals in an atom increase? 2. Write on the chalkboard the electronic configurations of potassium and calcium with atomic	The following responses are expected from students: 1. The energy levels of the orbitals increase in the direction of the arrows in the chart. 2. The electronic configurations are as follows: $_{19}\text{K}:\ 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$

Teacher's Activities	Students' Activities
numbers 19 and 20 respectively.	$_{20}$Ca: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

Third Lesson Plan for "Models Only" Group

Topic: Electronic Configurations of Elements

Duration: 40 minutes

Assumed Previous Knowledge: Students know that according to the Aufbau Principle, some electrons occupy lower-energy levels in an atom before others occupy higher-energy levels. They also know the representation of an orbital by the use of the principal quantum number and the type of orbital. Moreover, they know that all orbitals of the same type in a given shell are degenerate.

Objectives: By the end of the lesson students should be able to:

(i) apply Hund's Rule of Maximum Multiplicity to state the order in which degenerate orbitals are occupied by electrons;

(ii) apply Hund's Rule of Maximum Multiplicity, the Aufbau Principle and the order for filing all orbitals with electrons to state the electronic configurations of elements whose atomic numbers are known.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. State the Aufbau Principle.	1. Electrons always enter the lowest empty energy level in an atom.

Teacher's Activities	Students' Activities
	L-shell: 2s orbital 2p orbitals M-shell: 3s orbital 3p orbitals 3d orbitals
3. What are the degenerate orbitals in the L-shell?	3. The degenerate orbitals in the L-shell are the $2p_x$, $2p_y$ and $2p_z$ orbitals.
<u>Development</u>: <u>Hund's Rule of Maximum Multiplicity (20min)</u>: Teacher explains to students Hund's Rule of Maximum Multiplicity. Teacher mounts on metal rods before the class two wooden discs for demonstrating the opposite spins of the electron pair in an orbital. Teacher also arranges physical models of the	Students listen to teacher and observe the models.
p-orbitals and asks students to respond to the following:	Responses such as the following are expected from students:
1. Looking at the models, what difference do you observe among the three p-orbitals?	1. The three p-orbitals have different orientations.
2. Does the energy level of a p-orbital depend upon its orientation?	2. The energy level of a p-orbital does not depend upon its orientation.

Teacher's Activities	Students' Activities
3. What is the relationship among the three p-orbitals of the same shell in terms of energy level?	3. All the three p-orbitals of the same shell are at the same energy level
4. Turn one of the wooden discs for demonstrating electron spin. What effect does this have on the other disc?	4. (A student turns one of the discs.) It causes the other disc to turn at the same speed in the opposite direction.
5. What, then, is the relationship between the spins of the electron pair in an orbital?	5. The spins of the electron pair in an orbital are equal and opposite.
6. If the three p-orbitals of the same shell are empty and are to be filled with six electrons, in what manner will they be filled?	6. All the three p-orbitals will first be occupied by single electrons before the rest of the electrons are distributed over them to pair up with those that have already occupied them.
7. What is the relationship among the spins of the first set of single electrons that occupy these orbitals?	7. The first set of single electrons in the orbitals spin in the same direction.
8. What is the relationship between the spins of the electron pair in the same orbital?	8. The spins of the electron pair in the same orbital are equal and opposite.

Teacher's Activities	Students' Activities
9. Write the detailed electronic configurations of nitrogen, oxygen, sodium and chlorine with atomic numbers 7, 8, 11 and 17 respectively.	9.The electronic configurations are as follows: ${}_{7}\mathrm{N}$: $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^1$ ${}_{8}\mathrm{O}$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1\ 2p_z^1$ ${}_{11}\mathrm{Na}$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^1$ ${}_{17}\mathrm{Cl}$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2$ $3p_x^2\ 3p_y^2\ 3p_z^1$
Teacher explains to students that just as Hund's Rule of Maximum Multiplicity applies to the filling of all the three p-orbitals of a shell, it also applies to the filling of all the five d- or seven f-orbitals of a shell with electrons.	Students listen to teacher and take down notes.
The Order for Filling All the Orbitals with Electrons (5min): Teacher summarizes the order for filling all the orbitals with electrons by drawing the chart of Fig. 5 on the chalkboard.	Students listen, observe and draw the chart presented by teacher.
Closure (10min): Teacher asks students to respond to the following:	The following responses are expected from students:
1. From the chart drawn on the board, what is the order in which the energy	1. The energy levels of the orbitals increase in the direction of the

Teacher's Activities	Students' Activities
levels of all the orbitals in an atom increase?	arrows in the chart.
2. Write on the chalkboard the electronic configurations of potassium and calcium with atomic numbers 19 and 20 respectively.	2. The electronic configurations are as follows: $_{19}K$: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$ $_{20}Ca$: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

Third Lesson Plan for "Diagrams and Models" Group

Topic: Electronic Configurations of Elements

Duration: 40minutes

Assumed Previous Knowledge: Students know that according to the Aufbau Principle, some electrons occupy lower-energy levels in an atom before others can occupy higher-energy levels. They also know the representation of an orbital by the use of the principal quantum number and the type of orbital. Moreover, they know that all orbitals of the same type in a given shell are degenerate.

Objectives: By the end of the lesson students should be able to

(i) apply Hund's Rule of Maximum Multiplicity to state the order in which degenerate orbitals are occupied by electrons.

(ii) apply Hund's Rule of Maximum Multiplicity, the Aufbau Principle and the order for filling all orbitals with electrons to state the electronic configurations of elements whose atomic numbers are known.

Teacher's Activities	Students' Activities
Introduction (5min):	
Teacher asks students to respond to the following:	Students are expected to give the following responses:
1. State the Aufbau Principle.	1. Electrons always enter the lowest empty energy level in an atom.
2. How would you represent the orbitals in the K-, L- and M-shells of an atom?	2. The orbitals in the shells are as follows: K-shell: 1s orbital L-shell: 2s orbital 2p orbitals M-shell: 3s orbital 3p orbitals 3d orbitals
3. What are the degenerate orbitals in the L-shell?	3. The degenerate orbitals in the L-shell are the $2p_x$, $2p_y$ and $2p_z$ orbitals.
Development:	
Hund's Rule of Maximum Multiplicity (20min): Teacher explains to students Hund's Rule of Maximum Multiplicity. He then displays before the class posters of the three p-orbitals and the sign [↿⇂]	Students listen to teacher and observe the posters and models.

Teacher's Activities	Students' Activities
and mounts on metal rods before the class two wooden discs for demonstrating the opposite spins of the electron pair in an orbital. Teacher also arranges physical models of the p-orbitals and asks students to respond to the following:	
1. Looking at the models, what difference do you observe among the three p-obitals?	1. The three p-orbitals have different orientations.
2. Does the energy level of a p-orbital depend upon its orientation?	2. The energy level of a p-orbital does not depend upon its orientation.
3. What is the relationship among the three p-orbitals of the same shell in terms of energy level?	3. All the three p-orbitals of the same shell are at the same energy level.
4. Turn one of the wooden discs for demonstrating electron spin. What effect does this have on the other disc?	4. (A student turns one of the discs). It causes the other disc to turn at the same speed in the opposite direction.
5. What, then, is the relationship between the spins of the electron pair in an orbital?	5. The spins of the electron pair in the same orbital are equal and opposite.

Teacher's Activities	Students' Activities
6. If the three p-orbitals of the same shell are empty and are to be filled with six electrons, in what manner will they be filled?	6. All the three p-orbitals will first be occupied by single electrons before the rest of the electrons are distributed over them to pair up with those that have already occupied them.
7. What is the relationship among the spins of the first set of single electrons that occupy these orbitals?	7. The first set of single electrons in the orbitals spin in the same direction.
8. What is the relationship between the spins of the electron pair in the same orbital?	8. The spins of the electron pair in the same orbital are equal and opposite.
9. Write the detailed electronic configurations of nitrogen, oxygen, sodium and chlorine with atomic numbers 7, 8, 11 and 17 respectively.	9. The electronic configurations are as follows: $_7N$: $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^1$ $_8O$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1\ 2p_z^1$ $_{11}Na$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^1$ $_{17}Cl$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^1$
Teacher explains to students that just as Hund's Rule of Maximum Multiplicity applies to the filling of	Students listen to teacher and take down notes.

Teacher's Activities	Students' Activities
all the three p-orbitals of a shell, it also applies to he filling of all the five d- or seven f-orbitals of a shell with electrons.	
The Order for Filling All the Orbitals with Electrons (5min):	
Teacher summarizes the order for filling all the orbitals with electrons by drawing the chart of Fig. 5 on the chalkboard.	Students listen, observe and draw the chart presented by teacher.
Closure (10min):	
Teacher asks students to respond to the following:	The following responses are expected from students.
1. From the chart drawn on the board, what is the order in which the energy levels of all the orbitals in an atom increase?	1. The energy levels of the orbitals increase in the direction of the arrows in the chart.
2. Write on the chalkboard the electronic configurations of potassium and calcium with atomic numbers 19and 20 respectively.	2. The electronic configurations are as follows: $_{19}\mathrm{K}$: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$ $_{20}\mathrm{Ca}$: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

Data Analysis

The procedures used to test the two hypotheses and to answer the research question are in three phases. The first phase involved one-way analysis of covariance (ANCOVA) on the posttest scores (dependent variable) using students' pretest scores as covariate. The independent variable was the type of teaching method, which involved diagrams only, models only, and a combination of diagrams and models. ANCOVA was used to find out whether the differences in posttest mean scores depended significantly on the type of teaching method. Post-hoc tests were carried out to find out which of the student groups had a significant difference in their posttest mean scores.

The second phase of the analysis involved the use of the McNemar chi-square test to test for the significance of changes in misconceptions from the pretest to the posttest in each group. In this test the McNemar chi-square (χ^2) was calculated for the change in the percentage of students with misconceptions on each item, and this led to the test of significance of the change.

In the third phase the specific misconceptions of students in each of the three groups on each item in both the pretest and posttest were analyzed qualitatively. The number and percentage of students in each group that expressed a particular misconception in each test were determined. This facilitated observation of the way specific misconceptions remained or changed among each student group as a result of the treatment given.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

In this chapter the results obtained from the analysis of students' pretest and posttest scores are presented and discussed in relation to the two hypotheses and one research question. The pretest and posttest scores are shown in Appendices J and K respectively.

Performance of Students in a Test on Atomic Orbitals

The first hypothesis states that there is no significant difference among posttest mean scores of student groups that are instructed on atomic orbitals using teaching methods, which employ diagrams only, models only, and a combination of diagrams and models. The ANCOVA test was used to test this hypothesis, and the results are presented in Table 5. The independent variable, teaching method, included three levels: diagrams only, models only, and diagrams and models. The dependent variable was the students' achievement of posttest on atomic orbitals, and the covariate was the students' achievement of pretest on atomic orbitals. The ANCOVA test was significant, F(2,119) = 53.62, MSE = 146.922, p = 0.001. The null hypothesis was therefore rejected. This means that there were significant differences among the three groups. The means of the posttest scores adjusted for initial differences were ordered as expected across the three teaching methods. The "models only" group had the largest adjusted mean

Table 5

Results of the ANCOVA Test on Students' Posttest Scores

Source	df	Mean Square	F	Sig	Eta Squared
Intercept	1	802.625	292.91	0.001	0.71
Pretest	1	16.337	5.96	0.016	0.05
Group	2	146.922	53.62	0.001	0.47
Error	119	2.740			
Total	123				

df = degrees of feedom

$F = \frac{\text{Group mean square}}{\text{Error mean square}}$

Eta-squared = proportion of variation in posttest score that was due to the teaching method

(M = 5.98); the "diagrams and models" group had a smaller adjusted mean (M = 4.91), and the "diagrams only" group had the smallest adjusted mean (M = 2.22), as shown in Table 6. According to Table 5, the relationship between the type of teaching method and the test scores was also very strong, as assessed by a partial eta square, with the type of teaching method accounting for 47% of the variance of the dependent variable, holding constant the pretest scores. Follow-up tests were conducted to evaluate pairwise differences among the adjusted means. The Holm's Sequential Bonferroni procedure was used to control for Type I error across the pairwise comparisons. Table 7 shows the pairwise comparisons among the groups. All comparisons were significant: the comparison between the "models

Table 6

Adjusted Posttest Mean Scores for the Three Treatment Group

Group	Adjusted Mean (M)	SD
"Diagrams only"	2.22	1.74
"Models only"	5.98	1.81
"Diagrams and Models"	4.91	2.01

Table 7

Pairwise Comparisons of Adjusted Posttest Mean Scores among the Three Treatment Groups

Groups Compared	Source	df	Mean square	F	sig
"Models only" versus	Contrast	1	261.814	95.112	0.001*
"Diagrams only"	Error	119	2.753		
"Diagrams and models"	Contrast	1	111.881	40.644	0.001*
versus "Diagrams only"	Error	119	2.753		
"Models only" versus	Contrast	1	12.574	4.568	0.035*
"Diagrams and models"	Error	119	2.753		

only" and "diagrams only" groups, p (= 0.001) is less than 0.0167; the comparison between the ""diagrams and models" and "diagrams only" groups, p (= 0.001) is less than 0.025; the comparison between the "models only" and "diagrams and models" groups, p (= 0.035) is less than 0.05. This means that there were significant differences in the adjusted means among all the three groups. Thus, students instructed on atomic orbitals using models only achieved significantly better on the atomic orbital test than their counterparts, who were instructed using diagrams and models and diagrams only in that order.

Students' Misconceptions about Atomic Orbitals

The second hypothesis states that there are no significant changes in misconceptions about atomic orbitals for groups of students instructed using diagrams only, models only, or a combination of diagrams and models. This hypothesis was tested using the McNemar chi-square test to determine the degrees of significant changes in students' misconceptions from the pretest to the posttest for each item. The types of misconceptions students held on each item were also analysed. The results are shown in Tables 8 to 26 and discussed item by item. In each table, "n" refers to the total number of students in each group. For Tables 9 to 26, "No" refers to the number of students that gave each misconception in the test. The percentage (%) of this number out of the group is also given. The misconceptions in the discussion are wrong views expressed by students on definitions, descriptions and interpretations of phenomena related to atomic orbitals. Therefore, wrong responses, which are not misconceptions, are not included in this discussion.

Item 1

The first item in each test was to find out whether students could state the shape of the s-orbital as spherical. Table 8 shows that, for this item, the proportion of students with misconceptions decreased significantly in all three groups. The drop in the proportion of students with misconceptions after the treatment was however, highest in the "models only" group (42.4% to 0%), followed by the "diagrams and models" group (26.1% to 2.2%) and the "diagrams only" group (34.1% to 15.9%). None of the students in the

Table 8

Changes in Misconceptions on Each Item among Different Student Groups

Item No.	Student Groups								
	"Diagrams Only" (n = 44)			"Models Only" (n = 33)			"Diagrams and Models" (n = 46)		
	Pretest	Posttest	McN χ^2	Pretest	Posttest	McN χ^2	Pretest	Posttest	McN χ^2
1	15(34.1)	7(15.9)	4.0*	14(42.4)	0(0)	14.0*	12(26.1)	1(2.2)	11.0*
3	15(34.1)	12(27.3)	0.8	10(30.3)	3(9.1)	7.0*	3(6.5)	5(10.9)	2.0
4	7(15.9)	9(20.5)	0.3	4(12.1)	0(0)	4.0*	11(23.9)	2(4.3)	6.2*
5	4(9.1)	18(40.9)	10.9*	7(21.2)	2(6.1)	2.8	12(26.1)	1(2.2)	11.0*
6	14(31.8)	20(45.5)	6.0*	8(24.2)	11(33.3)	1.8	9(19.6)	27(58.7)	18.0*
7	6(13.6)	4(9.1)	0.5	2(6.1)	9(27.3)	7.0*	11(23.9)	14(30.4)	1.3
8	22(50.0)	24(54.5)	0.3	5(15.2)	7(21.2)	0.5	2(4.3)	12(26.1)	8.3*
9	8 (18.2)	23(52.3)	15.0*	0(0)	1(3.0)	1.0	3(6.5)	10(21.7)	7.0*
10	16(36.4)	21(47.7)	5.0*	7(21.2)	2(6.1)	5.0*	2(4.3)	5(10.9)	1.8

Item 2 in the pretest and posttest were not parallel. Hence, no changes in misconception were analysed. Figures in parentheses are percentages of students. *Significant, $p < 0.05$

"models only" group continued to have misconceptions on the shape of the s-orbital.

Table 9 shows the specific misconceptions of the students in the first pretest item. The table shows that a third of the students had one misconception or the other about the shape of the s-orbital in the pretest, with the highest proportion of students being in the "models only" group. The major misconception in the pretest seems to be the view that the s-orbital was circular, round or oval. This misconception was held by 18.2% of students in the "models only" and "diagrams only" groups and 17.4% of students in the "diagrams and models" group.

Table 9

Misconceptions Expressed by Students on the First Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Circular / Round / Oval	8	18.2	6	18.2	8	17.4
Dumbbell-shaped	1	2.3	2	6.1	4	8.7
s-shaped	3	6.8	2	6.1	0	0
Others	3	6.8	4	12.1	0	0

Table 10 shows that, with the exception of one student in the "diagrams only" group, all students in the "models only" and "diagrams and models" groups dropped this misconception after the treatments. However, the proportion of students, who held the view that the s-orbital was dumbbell-shaped in the "diagrams only" group, increased after treatment (Table 9 and Table 10).The trend in the changes in misconceptions on the shape of the s-orbital among the various groups seems to suggest that the use of models gave students a clearer view of the shape of this orbital than the use of diagrams. This is supported by the claim of Glynn and Russell (1997) that models, especially physical ones, strengthen students' understanding of concepts when they are used in the classroom. The trend also suggests that the combination of the diagram with the model of the s-orbital had a negative effect on some students' visualization of the shape of the orbital.

Table 10

Misconceptions Expressed by Students on the First Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Oval	1	2.3	0	0	0	0
Dumbbell-shaped	3	6.8	0	0	1	2.2
s-shaped	2	4.5	0	0	0	0
Symmetrical	1	2.3	0	0	0	0

Item 2

The second item in the pretest was to find out whether students could mention directions of spin as the characteristics that distinguish between electrons in the same orbital. On the other hand, the corresponding item in the posttest was to find out whether they could explain the spin of an electron as its rotation on its axis. Thus, the second item in one test required a different response from that in the other test, although each item needed information about the same concept, which is electron spin. Hence, the

McNemar chi-square test was not carried out to look for changes in misconception.

Tables 11 and 12 show students' misconceptions on the pretest and posttest items. From Table 11, the misconception common to all groups in the pretest was the view that the electrons in the same orbital differ from each other in their energy levels, activation energies or ionization energies, the proportion of students expressing this view being highest in the "diagrams only" group (15.9%) and lowest in the "diagrams and models"

Table 11

Misconceptions Expressed by Students on the Second Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Their energy levels/ Activation energies/ Ionization energies	7	15.9	5	15.1	2	4.3
Positive and negative Electrons / Their signs	2	4.5	0	0	0	0
Their sub-orbitals	3	6.8	0	0	0	0
Their shapes/their Directions of Orientation	1	2.3	0	0	4	8.7
Others	1	2.3	0	0	2	4.3

group (4.3%). The expression of this misconception among all the three groups indicates that students did not know that the two electrons in the same orbital are at the same energy level.

Table 12

Misconceptions Expressed by Students on the Second Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Orientation of the electron	1	2.3	0	0	11	23.9
Energy level of the electron	1	2.3	0	0	0	0
Position of the electron in an atom	0	0	0	0	1	2.2
Direction of movement by the electron	3	6.8	0	0	11	23.9
Others	1	2.3	2	6.1	4	8.7

The explanation of the spin of an electron as the orientation of the electron by 2.3% of students in the "diagrams only" group and 23.9% of those in the "diagrams and models" group in the posttest shows that some students in these groups confused the spin of an electron with the orientation of an orbital (Table 12). This table shows that generally the proportion of students expressing misconceptions about the meaning of electron spin after the treatments was very low among the "models only" group compared with the other groups, in which diagrams were used in the teaching. The use of diagrams therefore must have confused some students by not illustrating the spin of an electron clearly enough.

Item 3

The third item in each test was to find out whether students understood that the two electrons in the same orbital have equal and opposite spins. Table 8 shows a significant decrease in the percentage of students with misconceptions on this item from the pretest to the posttest in the "models only" group ($\chi^2 = 7.0$, $p < 0.05$). There were however, no significant changes in the "diagrams only" and "diagrams and models" groups.

The specific misconceptions of students in the pretest are shown in Table 13. The misconception mostly expressed in the "diagrams only" group was the view that electrons in the same orbital move to and fro. However, as shown in Table 14, students dropped this view after treatment. In the "models only" group, most of the students with misconceptions in the pretest described the electrons in the same orbital either as reversible or as being in an equilibrium state (21.2%). This view was also dropped after treatment. One student in the "diagrams and models" group expressed the view that such electrons have different orientations. This is a misconception because it appears there was confusion between the spin of an electron and the orientation of an orbital. Whereas the student in this group gave up this view after treatment, Table 14 shows that some students in the other groups

Table 13

Misconceptions Expressed by Students on the Third Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
The electrons move to and fro.	3	6.8	0	0	0	0
The electrons are reversible / in an equilibrium state.	1	2.3	7	21.2	0	0
The electrons have different energy levels.	0	0	1	3.0	0	0
The electrons have different orientations.	0	0	0	0	1	2.2
One electron is positive and the other, negative.	1	2.3	0	0	0	0
Others	10	22.7	2	6.1	2	4.3

took it up. A look at this table reveals that, generally, the "models only" group had the smallest number of members showing misconceptions on electron spin after treatment, whilst the "diagrams only" group had the largest number. This trend suggests that the models used to demonstrate the spins of the electron pair in an orbital gave students a clearer view of the spins than the use of a pair of opposite arrows [↑↓].

Table 14

Misconceptions Expressed by Students on the Third Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
The electrons have different energy levels / quantum numbers.	3	6.8	0	0	0	0
The spins of the electrons have different shapes / opposite orientations.	2	4.5	1	3.0	0	0
The spins are alike /the same.	2	4.5	2	6.1	3	6.5
Others	5	11.4	0	0	2	4.3

Item 4

The fourth item in each test was to find out whether students could state that the angle between the directions of orientation of the p_x- and p_y-orbitals of an atom is 90°. Table 8 shows significant decreases in the proportion of students with misconceptions on this item from the pretest to the posttest only in the "models only" (12.1 to 0%) and "diagrams and models" (23.9% to 4.3%) groups. There was no significant change in this respect within the "diagrams only" group ($\chi^2 = 0.3$, $p > 0.05$). The table also shows that, after the treatments, all misconceptions on the item were dropped within the "models only" group whilst students in the other two groups continued to hold some misconceptions.

Table 15 gives the specific misconceptions of students on the item in the pretest. The main misconception common to all groups in the pretest was the view that the p_x- and p_y- orbitals are oriented at 45° to each other.

Table 15

Misconceptions Expressed by Students on the Fourth Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
30°	2	4.5	1	3.0	0	0
45°	4	9.1	1	3.0	7	15.2
60°	0	0	1	3.0	1	2.2
105.4°	0	0	0	0	1	2.2
180°	0	0	0	0	2	4.3
Acute angle	1	2.3	0	0	0	0
Reflex angle	0	0	1	3.0	0	0

The largest proportion of students expressed this view in the "diagrams and models" group (15.2%), followed by the "diagrams only" group (9.1%) and the "models only" group (3.0%) in that order. According to Table 16, more students in the "diagrams only" group (15.9%) took up this view after the treatment, whereas most of the students in the "diagrams and models" group and the student in the "models only" group dropped it.

Table 16

Misconceptions Expressed by Students on the Fourth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
30°	1	2.3	0	0	0	0
45°	7	15.9	0	0	1	2.2
60°	0	0	0	0	1	2.2
180°	1	2.3	0	0	0	0

Thus, after treatment, no student in the "models only" group held this view, but one or more students held it in the other groups. This trend of changes tends to suggest clearer representation of the angle between the p_x- and p_y- orbitals by the use of models than diagrams, and the contrast must be due to the three-dimensional nature of the physical models and the two-dimensional nature of the surface on which the diagrams were drawn. This is also supported by the claim of Glynn and Russell (1997) that models strengthen students' understanding of concepts.

Comparison of Tables 15 and 16 shows that the pretest misconceptions that the p_x- and the p_y- orbitals are oriented at 105.4°, an acute angle, and a reflex angle were completely dropped in all groups after the treatments. Thus, there were fewer students with misconceptions, on the whole on the fourth item, after the treatments than before. However, a new misconception appeared in the "diagrams only" group, and this was the view that the degenerate p-orbitals are oriented at 180° with each other.

Item 5

The fifth item in the pretest was to find out whether students could state that the angle between the directions of orientation of the p_x- and p_z-orbitals is 90°. In the posttest, it was to find out whether students could state the angle between the directions of orientation of the p_y- and p_z- orbitals also as 90°. Table 8 shows a significant increase in the percentage of students with misconceptions on this item from the pretest to the posttest in the "diagrams only" (9.1% to 40.9%) group and a significant decrease in the "diagrams and models" group (26.1% to 2.2%). However, there was no significant change in the case of the "models only" group ($\chi^2 = 2.8$, $p > 0.05$).

According to Table 17, one specific misconception common to all three groups in the pretest was the view that the angle between the p_x- and p_z-orbital orientations is 45°, as in the case of the fourth item. The largest proportion of students held this view in the "diagrams and models" (6.5%) group whilst the smallest proportion held it in the "models only" (3.0%) group. Tables 17 and 18 show that, whereas the percentage of students expressing this view in the "models only" or "diagrams and models" group either remained unchanged or dropped from the pretest to the posttest, the percentage of students increased in the "diagrams only" groups. The trend of changes in this misconception among the groups tends to strengthen the suggestion in the case of the fourth item that the models represented the angle between any two degenerate p-orbitals more clearly than the diagrams. As a further illustration of this contrast, it can be observed from the two tables that the view that the angle between the directions of orientation of these types of orbitals is 60° was maintained by 2.3% of students in the "diagrams only" group but dropped by students in the other two groups.

Table 17

Misconceptions Expressed by Students on the Fifth Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No.	%	No.	%	No.	%
25^0	0	0	0	0	1	2.2
45^0	2	4.5	1	3.0	3	6.5
50^0	0	0	1	3.0	0	0
60^0	1	2.3	1	3.0	2	4.3
120^0	0	0	1	3.0	1	2.2
180^0	0	0	2	6.1	3	6.5
360^0	0	0	0	0	2	4.3
Acute angle	1	2.3	0	0	0	0
Obtuse angle	0	0	1	3.0	0	0

Table 18

Misconceptions Expressed by Students on the Fifth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
30^0	2	4.5	0	0	0	0
45^0	12	27.3	1	3.0	1	2.2
60^0	1	2.3	0	0	0	0
180^0	3	6.8	1	3.0	0	0

Item 6

The sixth item in each test was to find out whether students could state the direction of orientation in space as the characteristic that differentiates between degenerate orbitals. According to Table 8, the proportion of students with misconceptions increased from the pretest to the posttest in all three groups. The increase in the proportion of students with misconceptions was significant in the "diagrams only" and "diagrams and models groups ("diagrams only": $\chi^2 = 6.0, p < 0.05$; "diagrams and models": $\chi^2 = 18.0, p < 0.05$). In addition, the table shows high increases in the proportions of students with misconceptions in the "diagrams only" group (31.8% to 45.5%) and the "diagrams and models" group (19.6% to 58.7%). The increase in this respect in the "models only" group was however, lower (24.2% to 33.3%). These differences seem to suggest a negative impact of the use of diagrams on students' visualization of degenerate orbitals.

Tables 19 and 20 show specific misconceptions of students on item 6 in the pretest and posttest respectively. Comparison of these two tables shows the emergence of a new misconception across all three groups after the treatments, and this was the view that degenerate orbitals are differentiated from one another by their quantum numbers, spinning relationships or energy levels. The proportion of students, who expressed this view after the treatments, was highest in the "diagrams and models" group (39.1%), followed by the "diagrams only" group (22.7%) and the "models only" group (18.2%), as shown in Table 20. The view that degenerate orbitals are differentiated from one another by their numbers of electrons or shells was expressed in all three groups in the pretest (Table 19). However, Table 20 shows that students in the "models only" group gave up this view whilst those in the other groups maintained it after treatment, the proportion of students expressing this misconception dropping in the "diagrams only" group (11.4% to 4.5%) and rising in the "diagrams and models" group (6.5% to 17.4%). Similarly, students from all three groups expressed in the pretest the view that degenerate orbitals are differentiated from one another by their shapes. Whereas this view was dropped in the "models only" and "diagrams and models" groups, it was maintained in the "diagrams only" group by 4.5% of the students.

The trend of changes in specific misconceptions in the various groups of students appears to strengthen the suggestion of a negative impact of the use of diagrams on students' visualization of degenerate orbitals. In the "diagrams and models" group, students seem to have had complex and confusing mental models of such obitals when diagrams were combined with models. This is supported by the suggestion of Coll (1999b), Coll and Treagust (2000, 2001a, 2001b), Gillespie, Moog and Spencer (1996a, 1996b), Ogilvie (1990) and Tsaparlis (1997) that there is little point in teaching complex, abstract mental models at the high school (or SSS) level.

Table 19

Misconceptions Expressed by Students on the Sixth Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Shape of orbital	3	6.8	3	9.1	2	4.3
Number of electrons / shells	5	11.4	3	9.1	3	6.5
Size / mass number	2	4.5	2	6.1	0	0
Charge / electron affinity / nuclear attraction	2	4.5	0	0	3	6.5
Others	2	4.5	0	0	1	2.2

Table 20

Misconceptions Expressed by Students on the Sixth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Shape of orbital	2	4.5	0	0	0	0
Number of electrons / shells / sub-shells / atoms	2	4.5	0	0	8	17.4
Quantum number / spinning relationship / energy level	10	22.7	6	18.2	18	39.1
Distance between orbitals / distance between orbital and nucleus	1	2.3	1	3.0	0	0
Others	5	11.4	4	12.1	1	2.2

Item 7

The seventh item in each test was to find out whether students know that lower energy levels are occupied by electrons before higher energy levels, and that this is the rule followed when electrons are filling different energy levels (or non-degenerate orbitals). Table 8 shows that there was a significant increase in the percentage of students with misconceptions from the pretest (6.1%) to the posttest (27.3%) within the "models only" group only ($\chi^2 = 7.0$, $p < 0.05$).

The specific misconceptions expressed by students on the item in the pretest are shown in Table 21. There was no misconception common to all three groups in the pretest. The view that all non-degenerate orbitals are occupied by single electrons before paring up begins, was expressed in this test among the "models only" and "diagrams and models" groups. Tables 21 and 22 show that the proportion of students expressing this view increased in the "models only" group (3.0% to 6.1%) but decreased in the "diagrams and models" group (10.9% to 6.5%) after the treatments. Table 22 shows that one student from the "diagrams only" group also took up this view after treatment. Thus, generally, students seem to have confused non-degenerate orbitals with degenerate orbitals. This agrees with the suggestion of Palmer (1999, 2001) that in trying to maintain many mental models such as those of degenerate and non-degenerate orbitals, students expose their minds to confusion.

Table 21

Misconceptions Expressed by Students on the Seventh Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Higher energy levels are filled first.	1	2.3	0	0	3	6.5
Energy levels taking fewer electrons are filled first.	3	6.8	1	3.0	0	0
Single electrons occupy all non-degenerate orbitals before paring up begins.	0	0	1	3.0	5	10.9
Others	2	4.5	0	0	3	6.5

Table 22

Misconceptions Expressed by Students on the Seventh Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Higher-energy orbitals are filled first.	1	2.3	0	0	0	0
Single electrons occupy all non-degenerate orbitals before pairing up begins.	1	2.3	2	6.1	3	6.5
Non-degenerate orbitals are paired up.	0	0	1	3.0	0	0
The filling of the energy levels follows no rule.	0	0	2	6.1	0	0
Others	2	4.5	4	12.1	11	23.9

Item 8

The eighth pretest item was to find out whether students know the order (2s, 2p, 3s, 3p) in which orbitals are filled with electrons. The eighth posttest item was to find out whether students know this order (3p, 4s, 3d, 4p) in which these orbitals are filled. According to Table 8, there was a significant increase in the proportion of students with misconceptions (4.3% to 26.1%) in the "diagrams and models" group only ($\chi^2 = 8.3, p < 0.05$).

Table 23 shows the specific misconceptions of students in the pretest. It appears the main misconception was the view that the orbitals are filled with electrons in the order 2s, 3s, 2p, 3p. The largest proportion (29.5%) of students expressing this view was in the "diagrams only" group. The misconception here was that s-orbitals must be filled before p-orbitals, irrespective of their energy levels. From Table 24, the main misconception on the test item in the posttest was the view that those orbitals are filled in the order 3p, 3d, 4s, 4p, and this was expressed by more than one-fifth of students in the sample. The largest proportion of students (36.4%)

Table 23

Misconceptions Expressed by Students on the Eighth Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
2s, 3s, 2p, 3p	13	29.5	2	6.1	2	4.3
2p, 3p, 2s, 3s	7	15.9	2	6.1	0	0
3s, 2s, 2p, 3p	1	2.3	0	0	0	0
2p, 2s, 3p, 2s	1	2.3	1	3.0	0	0

expressing this view was again in the "diagrams only" group. On this item, students had the misconception that orbitals in the third shell of an atom must always be filled before those in the fourth shell. This misconception must have evolved as a result of the idea that generally, inner shells are filled before outer shells. Thus, it appears the treatments generally made students change their view from the s, p, d, f order of occupancy of orbitals to the K, L, M, N … order of occupancy of shells by electrons, the two being different mental models. This also agrees with the suggestion of Palmer (1999, 2001) that the keeping of many mental models by students exposes their minds to confusion.

Table 24

Misconceptions Expressed by Students on the Eighth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
3p, 4s, 4p, 3d	4	9.1	0	0	2	4.3
3p, 3d, 4s, 4p	16	36.4	5	15.2	5	10.9
3d, 4s, 3p, 4p	1	2.3	0	0	0	0
3p, 4p, 3d, 4s	1	2.3	0	0	0	0
4s, 3p, 4p, 3d	2	4.5	1	3.0	1	2.2
Others	0	0	1	3.0	4	8.7

Item 9

The ninth item in each test was to find out whether students know the rule that when degenerate orbitals are being filled with electrons, each of them must be occupied by a single electron before further electrons with spins equal and opposite to those of the first set can start pairing up with them. Table 8 shows significant increases in the percentage of students with misconceptions from the pretest to the posttest in the "diagrams only" (18.2% to 52.3%) and "diagrams and models" (6.5% to 21.7%) groups ("diagrams only": $\chi^2 = 15.0$, $p < 0.05$; "diagrams and models": $\chi^2 = 7.0$, $p < 0.05$). There was, however, no significant change in the "models only" group. Also more than one-half of the students in the "diagrams only" group expressed misconceptions on the ninth item after treatment.

The specific misconceptions of students in the pretest are shown in Table 25. There were no misconceptions common to all three groups in the pretest. However, some students in both the "diagrams only" (6.8%) and "diagrams and models" (2.2%) groups shared the misconception that one orbital is completely filled before the next one is occupied. Here, students failed to apply Hund's rule of maximum multiplicity, and this resulted in the misconception. Table 26 shows that this view was dropped in the "diagrams and models" group after the treatment. In the "diagrams only" group, however, the proportion of students that expressed it rather increased (6.8% to 9.1%). As shown in Table 25, a misconception expressed only by students in the "diagrams only" group in the pretest was the view that among degenerate orbitals, electrons fill lower-energy orbitals first. One student in this group implied this by stating that the Aufbau rule is followed. Tables 25 and 26 show a high increase in the proportion of students in the group that expressed this view after treatment (4.5% to 34.1%). Some students from the “diagrams and models” group also expressed this view after treatment. Students, who had this view, seem to have confused degenerate orbitals with non-degenerate ones, in which lower-energy orbitals are filled with electrons before higher-energy orbitals. The view of students in all three groups that degenerate orbitals are filled with single electrons was also expressed after the treatments. This is a misconception because no orbital is filled with a single electron. Rather, every orbital is filled with two electrons, and all degenerate orbitals are first occupied by single electrons before a second

Table 25

Misconceptions Expressed by Students on the Ninth Pretest Item

Misconception	Student Groups					
	“Diagrams Only” (n = 44)		“Models Only” (n = 33)		“Diagrams and Models” (n = 46)	
	No	%	No	%	No	%
Electrons fill lower-energy orbitals first / The Aufbau rule is followed.	2	4.5	0	0	0	0
One orbital is filled completely before the next one is occupied.	3	6.8	0	0	1	2.2
Others	3	6.8	0	0	2	4.3

electron starts to pair up with each of the first set (Hund's rule). It means therefore that students misrepresented Hund's rule of maximum multiplicity.

Table 26

Misconceptions Expressed by Students on the Ninth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
Lower-energy orbitals are occupied first / The Aufbau rule is followed.	15	34.1	0	0	4	8.7
One orbital is filled completely before the next one is occupied.	4	9.1	0	0	0	0
Degenerate orbitals are filled with single electrons.	1	2.3	1	3.0	1	2.2
Others	3	6.8	0	0	5	10.9

Item 10

The last pretest item was to find out whether students know the electronic configuration of the nitrogen atom in its ground state as $1s^2$ $2s^2$

$2p_x^1$ $2p_y^1$ $2p_z^1$. The last posttest item was to find out whether they also know the ground state electronic configuration of the carbon atom as $1s^2$ $2s^2$ $2p_x^1$ $2p_y^1$. Table 8 shows a significant increase in the proportion of students with misconceptions from the pretest (36.4%) to the posttest (47.7%) in the "diagrams only" group ($\chi^2 = 5.0$, $p < 0.05$). The table however, shows a significant decrease (from 21.2% to 6.1%) in the "models only" group ($\chi^2 = 5.0$, $p < 0.05$). There was no significant change in the proportion of students with this misconception in the "diagrams and models" group ($\chi^2 = 1.8$, $p > 0.05$).

Table 27 shows the specific misconceptions of students in the pretest. A misconception common to the "diagrams only" and "diagrams and

Table 27

Misconceptions Expressed by Students on the Tenth Pretest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models (n = 46)	
	No	%	No	%	No	%
$1s^2$ $2s^2$ $2p_x^2$ $2p_y^1$	1	2.3	0	0	1	2.2
$1s^2$ $2s^5$ / 2, 5 (First orbital: two electrons, second orbital: five electrons)	12	27.3	7	21.2	0	0
Others	3	6.8	0	0	1	2.2

models" groups in the pretest was the view that the electronic configuration of the nitrogen atom in its ground state is $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1$, as shown in Table 27. The misconception here is that students thought each orbital, even among degenerate orbitals, must be occupied by a pair of electrons before the next one is occupied. This view caused them to assign two electrons to the $2p_x$-orbital whilst the $2p_z$-orbital was not yet occupied, thus violating Hund's rule of maximum multiplicity. As shown in Table 28, students in both groups expressed a similar view in connection with carbon after the treatments by stating the ground state electronic configuration as $1s^2\ 2s^2\ 2p_x^2$ instead of $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1$. Comparison of Tables 27 and 28 shows a large increase in the proportion of students expressing this kind of misconception in the "diagrams only" group (2.3% to 13.6%). This misconception was also expressed by 3.0% of the students in the "models only" group after treatment (Table 28). Another misconception expressed by students in the "diagrams

Table 28

Misconceptions Expressed by students on the Tenth Posttest Item

Misconception	Student Groups					
	"Diagrams Only" (n = 44)		"Models Only" (n = 33)		"Diagrams and Models" (n = 46)	
	No	%	No	%	No	%
$1s^2\ 2s^2\ 2p_x^2$	6	13.6	1	3.0	1	2.2
$1s^2\ 2p_x^2\ 2p_y^2$	1	2.3	0	0	0	0
$1s^2\ 2s^2\ 3s^2$	3	6.8	0	0	0	0
Others	11	25.0	1	3.0	4	8.7

only" and "models only" groups in the pretest was the view that the ground state electronic configuration of the nitrogen atom is $1s^2 2s^5$ or simply (2, 5). Students who stated the electronic configuration as (2, 5) indicated that the first orbital contains two electrons whilst the second orbital contains five (Table 27). It seems that students who expressed these views used "orbitals" and "shells" interchangeably (Darkwa, 1999), because the simple electronic configuration (2, 5) gives the number of electrons in each of the first two shells rather than the first two orbitals. As shown in Table 28, all students in the two groups gave up this kind of misconception in connection with carbon after the treatments.

The trend of changes in misconceptions on the tenth item, and the relatively higher proportion of students with misconceptions on this item after the treatment in the "diagrams only" group compared with the other groups, suggest that the use of the models only was more effective than the use of the diagrams only in helping students visualize atomic orbitals and to write electronic configurations using them. The trend in the changes suggests also that when the diagrams and models were combined, the diagrams confused some students and had a negative effect on their understanding, which counteracted the positive impact of the models on their visualization.

Summary of Students' Misconceptions

The results of the McNemar chi-square test show that within each group, there were significant changes in misconceptions on some of the items. Thus, the null hypothesis was rejected. However, there were insignificant changes on other items.

The key misconception of students on the shape of the s-orbital before the treatments was that it is circular, round or oval. Comparison of Tables 9 and 10 shows that the "models only" group had the highest proportional drop in this view after treatment (18.2% to 0%), followed by the "diagrams and models" group (17.4% to 0%), and the "diagrams only" group (18.2% to 2.3%).

Also before treatment, the main misconception on the angle between any two of the p-orbitals at the same energy level was that it is 45°. Comparison of Tables 15 and 16 and Tables 17 and 18 reveals that generally, there were drops in the proportions of students with this view among the "models only" and "diagrams and models" groups, and a rise in the "diagrams only" group.

On the characteristic of degenerate orbitals that differentiates them from each other, students in all three groups expressed a new misconception after the treatments, this being the view that such orbitals are differentiated by their quantum numbers, spinning relationships or energy levels. Table 20 shows that the highest proportion of students expressed this view in the "diagrams and models" group, followed by the "diagrams only" group and the "models only" group.

Another misconception of students in the pretest was that s-orbitals are always filled with electrons before p-orbitals, irrespective of their energy levels. After treatment, there was a change from this view in all groups to the view that orbitals in the third shell of an atom must always be filled before those in the fourth shell. These views were shown in the order (2s, 3s, 2p, 3p) given in the pretest, and the order (3p, 3d, 4s, 4p) given in the posttest as the orders in which these orbitals are filled with electrons (Tables 23 and 24). In each test, the highest proportion of students that gave the misconception was in the "diagrams only" group.

On the whole, Table 8 shows that, for items on which groups showed significant changes in misconceptions, the "models only" group had a significant decrease on the largest number of items (four items), followed by the "diagrams and models" group (three items) and the "diagrams only" group (one item). The table shows also that the "diagrams only" group had a significant increase on the largest number of items (four items), followed by the "diagrams and models" group (three items) and the "models only" group (one item). It means that the use of models only was most effective in helping students drop their misconceptions on atomic orbitals; the use of diagrams and models was less effective, and the use of diagrams only, least effective. On the contrary, the use of diagrams only contributed most in increasing misconceptions in students, and it was followed by the use of diagrams and models and the use of models only in that order. This trend is supported by the claim of Eaton, et al (2001) that three-dimensional teaching aids (such as physical models) tend to help students understand key ideas better than two-dimensional teaching aids (such as diagrams). Again the trend of the results suggests that the combination of diagrams with the models tended to have a negative impact on students' understanding of ideas by confusing them. Coll (1999b), Coll and Treagust (2000, 2001a, 2001b), Gillespie, Moog and Spencer (1996a, 1996b), Ogilvie (1990) and Traparlis (1997) have supported this by suggesting that high school students do not benefit enough when teaching is made abstract (for instance, by the use of diagrams).

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

In this concluding chapter, the most important findings are presented, and some generalizations are offered for the teaching of chemistry using models. The limitations of the study are also indicated, and some suggestions made for future study.

Overview of the Research Problem and Methodology

The problem that prompted this study is that the concept of atomic orbital looks abstract to Ghanaian SSS students. One reason, which makes the concept abstract, is that orbitals are three-dimensional, but teachers use pictures and diagrams on posters to teach students. These same diagrams and pictures are in textbooks. The poster and chalkboard surfaces and the pages in textbooks are two-dimensional and, therefore, do not give students clear images of three-dimensional concepts such as orbitals. Eaton, et al (2001) have suggested that three-dimensional teaching aids explain concepts to students better than two-dimensional teaching aids.

This study was therefore carried out to compare the effectiveness of the use of diagrams only, models only, and a combination of diagrams and models in the teaching of atomic orbitals to SSS students in three selected schools. Intact second-year elective chemistry classes in three schools in the Cape Coast Municipality were selected for the study. Each class was given one of three treatments by the researcher. Data generation and collection were in three phases.

In the first phase, students were given a pretest on atomic orbitals using 10 objective items, which required them to supply their own responses. The second phase involved the treatments, in which the student groups were taught the concept of atomic orbital using the various sets of teaching aids. In the third phase, they were given a posttest on atomic orbitals using 10 objective items, which were parallel to the pretest items. The maximum score possible in each test was 10.

Summary of Key Findings

Achievements of Student Groups on Atomic Orbitals

The first hypothesis states that there is no significant difference among the posttest mean scores of student groups, which are taught the concept of atomic orbital using diagrams only, models only, and a combination of diagrams and models. An ANCOVA test on this hypothesis, using students' posttest scores as the dependent variable and their pretest scores as covariate, showed the presence of significant differences among the three groups. The null hypothesis was therefore rejected. The "models only" group had the largest adjusted mean, followed by the "diagrams and models" group and the "diagrams only" group in that order. Post-hoc tests evaluating pairwise differences among the adjusted posttest means showed significant differences in all three comparisons. It means therefore that students instructed on atomic orbitals using a combination of models only achieved significantly better than those instructed using diagrams and models, who in turn achieved significantly better than those instructed using diagrams only.

Changes in Misconceptions in Student Groups

The second hypothesis states that there are no significant changes in misconceptions about atomic orbitals for student groups, which are taught using diagrams only, models only, or a combination of diagrams and models. McNemar chi-square tests on the changes in misconceptions on the test items from the pretest to the posttest showed that each group had significant changes on some of the items. Hence, the null hypothesis was rejected also in this case. The misconceptions decreased significantly on the items mostly in the "models only" group, followed by the "diagrams and models" group and, then, the "diagrams only" group. However, in terms of a significant increase in misconceptions on the items, this order was reversed across the groups. Thus, the use of models only was the most effective method of helping students drop their misconceptions on atomic orbitals. However, the use of diagrams tended to confuse students and lead to an increase in their misconceptions on atomic orbitals.

Types of Misconception Observed in Student Groups

The research question seeks to find out the types of misconceptions students have before and after they are instructed on atomic orbitals using the various treatments. The key misconception of students on the shape of the s-orbital before treatment was that it is circular, round or oval. After treatment, the "models only" group had the highest proportion of its students dropping this view, followed by the "diagrams and models" group and, then, the "diagrams only" group. Some students also initially thought that the angle between any two degenerate p-orbitals was 45^0. Fewer students continued to hold this view in the "models only" and "diagrams and models" groups after treatment. On the other hand, more students adopted it in the "diagrams only" group. Also, before the treatments, students had the misconception that s-orbitals are always filled with electrons before p-orbitals, irrespective of their energy levels. This was replaced after treatment in all groups by the view that orbitals in the third shell of an atom are always filled before those in the fourth shell, students failing to recognize that the 4s-orbital, with lower energy, is filled before the 3d-orbitals. The "diagrams only" group had the highest proportion of its members expressing both misconceptions on the order in which the orbitals are filled. Finally, a new misconception expressed by a large proportion of students in all three groups after the treatments was the view that degenerate orbitals are differentiated from each other by their quantum numbers, spinning relationships or energy levels. The proportion of students expressing this view decreased from the "diagrams and models" group, through the "diagrams only" group, to the "models only" group.

Conclusion

It can be concluded from the results of this study that the use of physical models only as teaching aids helps explain atomic orbitals better and make their visualization by students clearer than the use of diagrams only. However, a combination of diagrams and models tends to confuse students and hamper their visualization as it becomes difficult for them to reconcile the images they observe from the two sets of teaching aids.

Recommendations

The following recommendations are offered:

1. The Ghana Association of Science Teachers (GAST) should educate its members, particularly those who are chemistry teachers, on the effectiveness of physical models, compared with diagrams, in the teaching of atomic orbitals to SSS students.
2. The Curriculum Research and Development Division (CRDD) of the Ghana Education Service should review the curriculum for chemistry teaching by emphasizing the use of three-dimensional physical models instead of two-dimensional diagrams in the teaching of atomic orbitals to SSS students.
3. The Departments of Science and Mathematics Education of the Universities of Cape Coast and Winneba should incorporate the development and use of physical models into chemistry methods courses.

Limitations of the Study

Inadequate time and financial resources restricted the study to three schools in the Cape Coast Municipality. The selection of schools by simple random sampling and the non-randomization of the students into the treatment groups limit the generalizability of the findings. However, the students, who took part in this study, were not different from most Ghanaian SSS students and, hence, the results could apply to students in other schools. The effectiveness of model-based teaching appears to be limited to young science students or beginners, who cannot visualize scientific concepts adequately.

Suggestions for Future Research

It is suggested that the study be replicated by another researcher, who will randomize students into the treatment groups and find out the outcome of that design. The study may also be extended to other abstract topics in chemistry such as molecular orbitals. Furthermore, it may be extended to cover d-orbitals for undergraduate students.

REFERENCES

Abraham, M. R & Williamson, V. M. (1995). The effect of computer animation on particulate mental modeis of college chemistry students. *Journal of Research in Science Teaching*, 32(5). 521 – 534.

Alves, F., Colinvaux, D., de Barros, H. L., Franco, C., Krapas & Queiroz. G. (1999). From scientists' and inventors' minds to some scientific and technological products: relationships between theories, models, mental models and conceptions. *International Journal of' Science Education*, 21(3). 277-291.

Ameyibor, K. & Wiredu, M. B. (1995). *Ghana Association of Science Teachers Chemistry for Senior Secondary Schools* (1st ed)., London: Unimax.

Borges, A.T.(1996). *Mental models of electromagnetism*. Unpublished Ph.D. Thesis, University of Reading.

Borges, A.T.& Gilbert, J. K. (1999). Mental models of electricity. *International Journal of Science Education*, 21 (2). 95 - 117.

Boulter, C.J., Elmer, R. & Gilbert, J. K. (2000). Positioning models in science education and in design and technology education. In C. J. Boulter & J.K. Gilbert,. *Developing Models in Science Education*. Dordrecht: Kluwer.

Boulter, C.J.& Gilbert, J. K. (1995). *Stretching models too far*. Paper Presented at the National Association for Research in Science Teaching (NARST) Annual Conference. San Fraricisco.

Boulter, C. J., Gilbert, J. K. Rutherford, M. (2000). Explanations with models in science education, In C. J. Boulter & J. K. Gilbert. *Developing Models in Science Education.* Dordrecht: Kluwer.

Britton, B. K., Glynn, S. M. & Yeany, R. H. (1991). A constructive view of learning science. In B. K. Britton, S. M. Glynn & R. H. Yeany. *The Psychology of Leaning Science.* Hillsdale, N. J.: Elbaum.

Brown, G. I. (1984). *Introduction to Physical Chemistry* (3rd ed). Essex: Longman.

Chalmers, A. F. (1999). *What is the Thing Called Science ?* Queensland: University of Queensland Press.

Chang, R. (1998). *Chemistry* (6th ed). Boston: Mc Graw-Hill.

Chi, M. T. H., De Leeuw, N. & Slotta, J. D. (1994). From things to processes: a theory of conceptual change for learning science concepts. *Learning and Instruction, 4.* 27 – 43.

Chittleborough, G., Mamiala, T. L. & Treagust, D. F.(2001). *The role of models and the development of scientific ideas in learning organic chemistry.* Paper Presented at the Annual Meeting of the NARST. St. Louis, Missouri.

Clement, J. (1998). Expert novice similarities and instruction using analogies. *International Journal of Science Education, 20* (10). 1271 – 1286.

Clement, J. (2000). Model based learning as a key research area for science education *International Journal of Science Education.* 22 (9). 1041 – 1053.

Coll, R.K (1999a). *Learners' mental models of chemical bonding.* Unpublished Doctor of Science Education Thesis, Curtin University of Technology, Perth.

Coll, R. K .(1999 b). *Learners' mental models of chemical bonding: a cross age study.* Paper Presented at the 30th Annual Conference of the Australasian Science Education Research Association. Rotorua, New Zealand.

Coll, R. K.& Taylor, N. (2001a). Alternative conceptions of chemical bonding by upper secondary and tertiary students. *Research in Science and Technology Education, 19* (2). 171 – 191.

Coll, R. K. & Taylor, N. (2001b). Alternative conceptions of chemical bonding amongst senior secondary and tertiary students: nature and origins. *Teaching and Learning, 22* (1). 48 – 60.

Coll, R. K. & Treagust, N. (2000). *Learners' mental models of metallic bonding: a cross-age study.* Paper Presented at the 31st Annual Conference of the Australasian Science Education Research Association. Freemantle .

Coll, R. K. & Treagust, D. F. (2001a). Learners' mental models of ionic bonding. *Research in Science Education, 31.* 357 – 382.

Coll, R. K. & Treagust, D. F. (2001b). *Learners' mental models of ionic bonding: a cross-age study.* Paper Presented at the Annual NARST Meeting. St. Louis, Missouri.

Coll, R.K. & Treagust, D.F. (2002a). Learners' use of analogy and alternative conceptions for chemical bonding: a cross-age study. *Australian Science Teachers' Journal, 48 (1). 24-35*

Coll, R.K. & Treagust, D.F. (2002b). Exploring tertiary students' understanding of covalent bonding. *Research in Science and Technological Education, 20 (2). 241 – 268*

Darkwa, S.A. (1999). *Students' Identification and Application of Rules Governing the Filling of Atomic Orbitals.* Unpublished Post-Graduate Diploma of Education Project Work, University of Cape Coast, Cape Coast.

De Jong, O. & van Driel, J. (2001). *Developing pre-service teachers' content knowledge and pedagogical content knowledge of models and modelling.* Paper Presented at the Annual Meeting of the NARST. St. Louis Missouri.

Driver, R., Leach, J., Scott, P. & Wood-Robinson, V. (1994). Young people's understanding of science concepts: implications of cross-age studies for curriculum planning. *Studies in Science Education*, 24. 75-100.

Duit, R. & Glynn, S.M. (1995). *Learning Science in the Schools: Research Reforming Practice*. New Jersey: Lawrence Erbium.

Duit, R. & Pfundt, H. (1994). *Bibliography: Students' Alternative Frameworks and Science Education (3rd ed).* Kiel: University of Kiel.

Duit, R. &Pfundt, H. (1997). *Bibliography: Students' Alternative Frameworks and Science Education* (4th ed). Kiel: University of Kiel.

Eaton, S., Evans, M., Ratcliffe, M., Smith, J., Tregidgo, D. & Wells, J. (2001). *Models in Teaching Chemistry – The Research Evidence.*. Southampton: Royal Society of Chemistry.

Eshach, H. & Garik, P. (2001). *Students' conception about atoms and atom building.* Paper Presented at the Annual Meeting of the NARST, St. Louis, Missouri.

Fischler, H. & Siefert, S. (2001).*How to help teachers and students to deal with models in science teaching.* Paper Presented at the Annual meeting of the NARST. St. Louis Missouri.

Gilbert, J. K. (1994). *Models and Modelling in Science Education.* Hatfield: Association for Science Education.

Gilbert, J. K. (1998). Explaining with models, In Ratcliffe, M. *Association For Science Education Guide to Secondary Science Education.* Cheltenham: Stanley Thrones.

Gilbert, J. K. & Justi, R. (2000). History and philosophy of science through models: some challenges in the case of the atom. *International Journal of Science Education, 22(9).* 993 – 1009.

Gilbert, J. K. & Justi, R.(2001). *Teachers' views about models and modelling in science education.* Paper Presented at the Annual Meeting of the NARST, St Louis, Missouri.

Gilbert, J. K. & Rutherford, M. (1998a). Models in explanation part 1: horse for courses? *International Journal of Science Education, 20*(1). 83 – 97.

Gilbert, J. K. & Rutherford, M. (1998b). Models in explanation part 2: whose voice? whose ears? *International Journal of Science Education, 20(2).* 187 – 203.

Gillespie, R. J., Moog. R. S. & Spencer, J. N. (1996a) Demystifying introductory chemistry part 1: electron configuration from experiment. *Journal of Chemical Education, 73* (7) 617 – 622.

Gillespie, R .J., Moog, R. S & Spencer, J. N. (1996b). Demystifying introductory to chemistry part 2: bonding and molecular geometry without orbitals – the electron domain model. *Journal of Chemical Education, 73* (7) 622 – 627.

Gil, V. M.(2001). Orbitals in chemistry: a modern guide for students. *Journal of Chemical Education ,78* (9). 1184.

Glynn, S. & Russell, A. (1997). *Teaching Science Concepts to Children: The Role of Models.* Georgia: Glynn.

Greca, I. M. & Moreira, M. A. (2000). Mental models, conceptual models and modelling. *International Journal of Science Education*, 22 (9). 1 – 11.

Grosslight, L., Jay, E., Smith, C. & Unger. C (1991). Understanding models and their use in science: conceptions of middle and high school students and experts. *Journal of Research in Science Teaching 28* (9). 799 – 822.

Harrison, A. G. & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: implications for teaching chemistry. *Science Education, 80*(5). 509 – 534.

Harrison, A. G. & Treagust, D.F.(2000). A typology for school science models. *International Journal of Science Education, 22* (9). 1011 – 1026.

Hawkes, S. J. (1996). Salts are mostly not ionized. *Journal of Science Education, 73* (5) 421 – 423.

Kask, U. & Rawn, J. D. (1993): *General Chemistry* (1st ed). Dubuque: Brown.

Keppel, G. (1991). *Design and Analysis: A Researcher's Handbook* (3rded). Englewood Cliffs: Prentice Hall.

Kneen, W. R., Rogers, M. J. W., Simpson, P. (1984). *Chemistry: Facts, Patterns and Principles* (1st ed). London: Addison-Wesley.

Mayer, R. E. (1992). Knowledge and thought: mental models that support scientific reasoning. In R. A. Duschl, & R. J. Hamilton. *Philosophy of Science, Cognitive Psychology and Educational Theory and Practice.* New York: Sunny Press. 226 – 243.

Ministry of Education (2003). *Teaching Syllabus for Senior High School Chemistry.* Accra: Curriculum Research and Development Division.

Ogilvie, J. F. (1990). The nature of chemical bonding. *Journal of Chemical Education, 67* (4). 280 – 289.

Oliva, P. F. (1992). *Developing the Curriculum* (3rd ed).New York: Harper Collins.

Olmsted, J. & Williams, G. M.(1994). *Chemistry: The Molecular Science* (1st ed). St. Louis: Mosby.

Palmer, D. H. (1999). Exploring the link between students' scientific and non-scientific concepts. *Science Education, 83.* 639 – 653.

Palmer,D.H. (2001). Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education, 23* (7). 691 – 706.

Pereira, M. P. & Pestana, M. E. M. (1991). Representations of models of water. *International Journal of Science Education,13* (3). 313 – 319.

Reiner, M. (2000). Thought experiments and embodied cognition. In C. J. Boulter, & J. K. Gilbert. *Developing Models in Science Education.* Dordrecht: Kluwer.

Rosenthal, R. & Rosnow, R. L. (1994). *Essentials of Behavioral Research: Methods of Data Analysis* (2nd ed). New York: McGraw-Hill.

Snyder, J. L. (2000).An investigation of the knowledge structure of experts, intermediates and novices in physics. *International Journal of ScienceEducation. 22* (9). 979 – 992.

Taber, K. S. (1995). An analogy for discussing progression in learning chemistry. *School Science Review, 76* (276). 91 – 95.

Taber, K.S. (1997). Student understanding of ionic bonding: molecular versus electrostatic framework. *School Science Review, 78* (285) 85 – 95.

Taber, K. S. (1998). An alternative conceptual framework from chemistry education. *International Journal of Science Education, 20* (5). 597 – 608.

Taber, K.S. (2000). Multiple frameworks? Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education, 22* (4) 399 – 417.

Taber, K. S. (2001). Shifting sand: a case study of conceptual development as competition between alternative conceptions. *International Journal of Science Education, 23* (7). 731 – 753.

Taber, K. S. & Watts, M. (1997). Constructivism and concept learning in chemistry: perspectives from a case study. *Research in Education, 58.* 10 – 20.

Tsaparlis, G. (1997). Atomic orbitals, molecular orbitals and related concepts: conceptual difficulties among chemistry students. *Research in Science Education, 27* (2). 271 – 287.

Van Driel, J. H. & Verloop, N. (1999). Teachers' knowledge of models and modelling in science. *International Journal of Science Education. 21(1).* 1141 – 1153.

Viennot, L. (1994). A multidimensional approach to characterize a conceptual "state" in students: the role played by questions. In D. Psillos. *European Research in Science Education, Proceedings of the Second Ph. D. Summer School.* Leptokaria, Greece.

Zimmermann, E. (2000). The structure and development of science teachers' pedagogical models: implications for teacher education. In C. J. Boulter & J. K. Gilbert. *Developing Models in Science Education.* Dordrecht, Kluwer.

APPENDIX A

SENIOR SECONDARY SCHOOLS OFFERING ELECTIVE CHEMISTRY IN THE CAPE COAST MUNICIPALITY IN 2003/2004

NAME OF SCHOOL	SEX OF STUDENTS
Adisadel College	Male
Aggrey Memorial Secondary School	Male and Female
Ghana National College	Male and Female
Holy Child School	Female
Mfantsipim School	Male
St. Augustine's College	Male
University Practice Secondary School	Male and Female
Wesley Girls' High School	Female

APPENDIX B

AGES OF STUDENTS IN EACH GROUP

"Diagrams Only" Group (n = 44)		"Models Only" Group (n = 33)		"Diagrams and Models" Group (n = 46)	
Student No.	Age in Years	Student No.	Age in Years	Student No.	Age in Years
1	17	1	16	1	16
2	17	2	16	2	18
3	16	3	17	3	17
4	16	4	16	4	17
5	16	5	16	5	16
6	17	6	16	6	16
7	18	7	18	7	16
8	16	8	17	8	16
9	16	9	17	9	16
10	18	10	16	10	16
11	16	11	16	11	16
12	17	12	16	12	17
13	16	13	16	13	16
14	16	14	16	14	16
15	16	15	17	15	17
16	16	16	16	16	16
17	17	17	16	17	16
18	16	18	16	18	16

APPENDIX B CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Age in Years	Student No.	Age in Years	Student No.	Age in Years
19.	16	19.	18	19.	16
20.	18	20.	18	20.	17
21.	17	21.	16	21.	16
22.	16	22.	16	22.	16
23.	16	23.	16	23.	16
24.	16	24.	16	24.	16
25.	16	25.	17	25.	18
26.	17	26.	16	26.	16
27.	16	27.	16	27.	16
28.	16	28.	16	28.	16
29.	16	29.	17	29.	16
30.	16	30.	16	30.	17
31.	18	31.	16	31.	16
32.	16	32.	18	32.	16
33.	16	33.	16	33.	17
34.	17			34.	17
35.	16			35.	17
36.	16			36.	16
37.	16			37.	16
38.	17			38.	16
39.	16			39.	17
40.	16			40.	16
41.	16			41.	16
42.	18			42.	17

APPENDIX B CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Age in Years	Student No.	Age in Years	Student No.	Age in Years
43.	16			43.	17
44.	16			44.	16
				45.	16
				46.	16

Mean Age = 16.43	Mean Age = 16.42	Mean Age = 16.35
Standard Dev = 0.69	Standard Dev = 0.70	Standard Dev = 0.56

APPENDIX C

THE PRETEST ITEMS AND THEIR EXPECTED RESPONSES

The Items

1. What is the shape of the s-orbital?
2. What are the characteristics that distinguish between electrons in the same orbital?
3. How will you describe the relationship between the electrons in the orbital below? $\boxed{\uparrow\downarrow}$

Questions 4 and 5 refer to orbitals at the same energy level. In each case, state the angle between the directions of orientation of the two orbitals stated.

4. p_x- and p_y-orbitals
5. p_x- and p_z-orbitals
6. When orbitals are at the same energy level, what makes them different from each other?
7. What is the rule followed when electrons are filling different energy levels.
8. Arrange the 3p-, 2p-, 3s- and 2s-orbitals in the order in which they are filled with electrons.
9. What is the rule followed when electrons are filling similar orbitals in an atom?
10. Write the electronic configuration of the nitrogen atom in its ground state, showing the number of electrons in each orbital.

Expected Responses

1. Spherical
2. Spins / Directions of spin / They have opposite (or different) spins. / They spin (or rotate or turn) in opposite (or different) directions.
3. They have <u>equal and opposite spins</u>. / They have <u>equal spins</u> in <u>opposite directions.</u>
4. 90°
5. 90°
6. Their orientations (in space). / They have different orientations (in space). / Their directions (are different).
7. Lower energy levels are filled before higher energy levels.
8. 2s, 2p, 3s, 3p.
9. All the similar orbitals are occupied by single electrons before any of them can be occupied by two electrons (with opposite spins).
10. $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^1$

Each correct response attracts one mark. Since the test is objective, a response is either correct or wrong.

APPENDIX D

THE POSTTEST ITEMS AND THEIR EXPECTED RESPONSES

The Items

1. What is the shape of the orbital with the lowest energy level in an atom?

2. What is meant by the spin of an electron?

3. What is the relationship between the spins of the electrons in the same orbital?

Questions 4 and 5 refer to orbitals in the same shell. In each case, write the value of the angle between the directions of the two orbitals stated.

4. p_x- and p_y-orbitals

5. p_y- and p_z-orbitals

6. What makes degenerate orbitals different from each other?

7. What is the rule followed when electrons are filling orbitals that are not degenerate?

8. Arrange the 3d-, 4p-, 4s- and 3p-orbitals in the order in which they are filled by electrons.

9. What is the rule followed when electrons are filling degenerate orbitals?

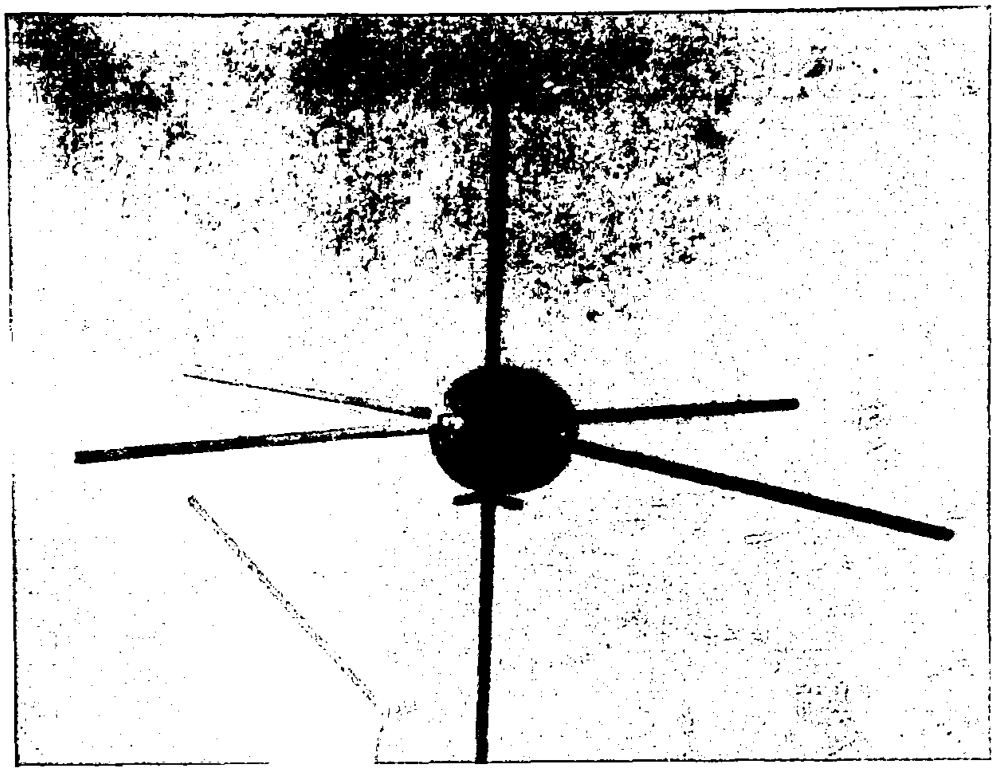
10. Write the electronic configuration of the carbon atom in the ground state, showing the number of electrons in each orbital.

Expected Responses

1. Spherical
2. The rotation (or turning) of the electron (on its axis) .
3. They are <u>equal and opposite.</u>
4. 90°
5. 90 °
6. The orientation (or direction) of each of them (in space) / They have different orientations (or directions) (in space).
7. Lower energy oribtals (or levels) are occupied by electrons before higher energy orbitals (or levels) are occupied.
8. 3p, 4s, 3d, 4p.
9. Each of the degenerate orbitals (or energy levels) is occupied by a single electron before any of them is occupied by two electrons (with opposite spins).
10. $1s^2\ 2s^2\ 2p_x{}^1\ 2p_y{}^1$ (or $1s^2\ 2s^2\ 2p_x{}^1\ 2p_y{}^1\ 2p_z{}^0$)

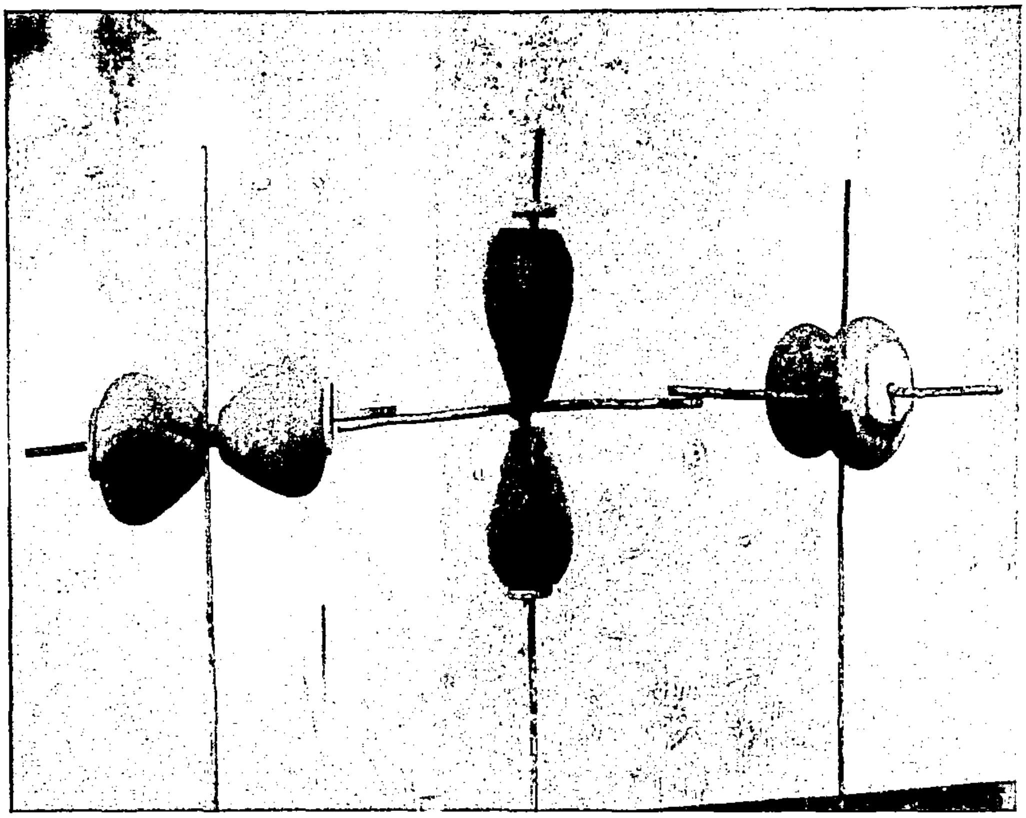
Each correct response attracts one mark. A response is either correct or wrong.

APPENDIX E



PHOTOGRAPH OF PHYSICAL MODEL OF THE s-ORBITAL USED IN THE TEACHING

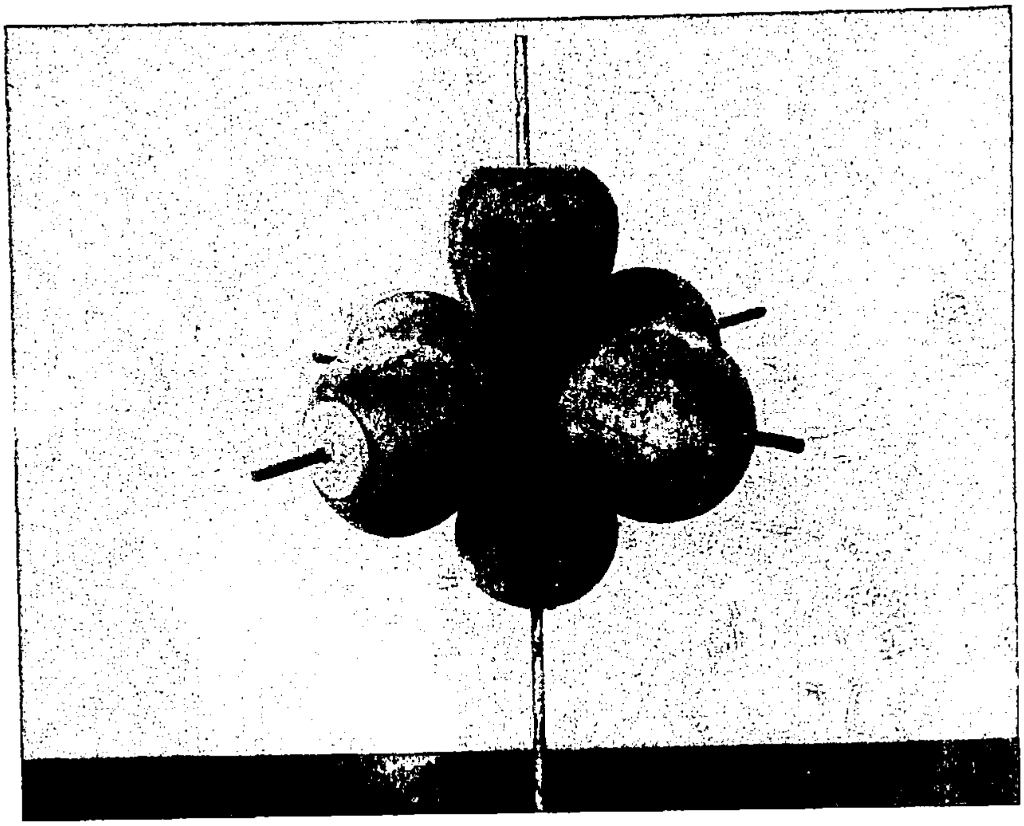
APPENDIX F



PHOTOGRAPH OF PHYSICAL MODELS OF THE THREE

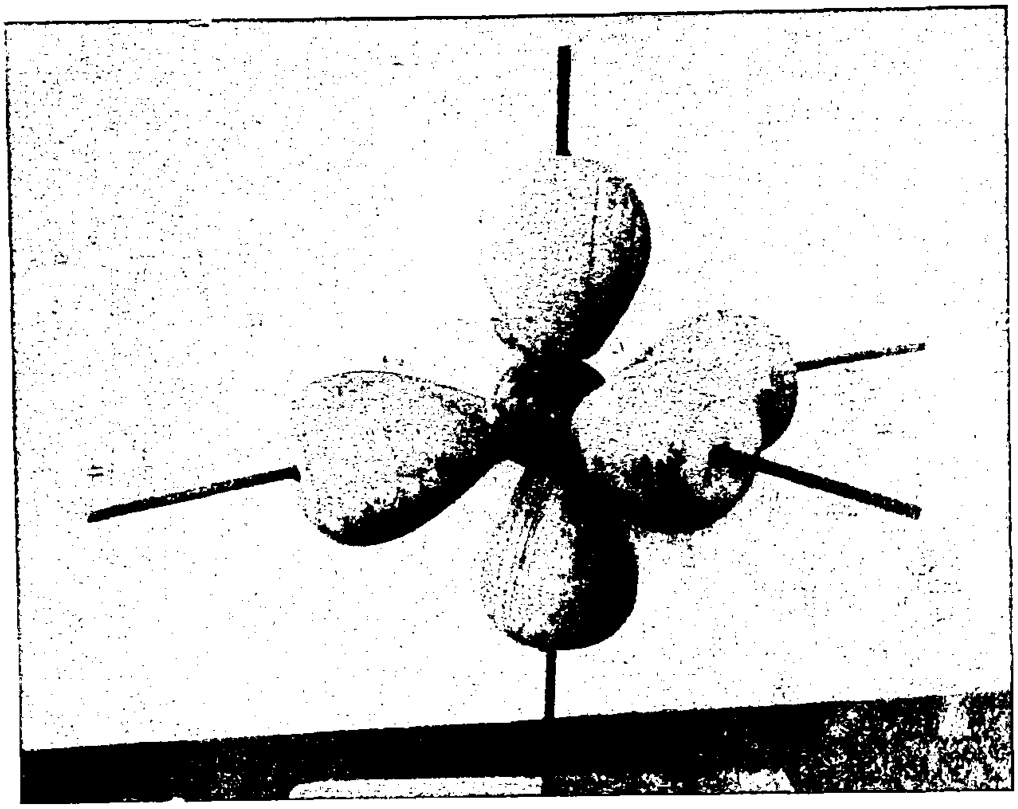
p-ORBITALS USED IN THE TEACHING

APPENDIX G



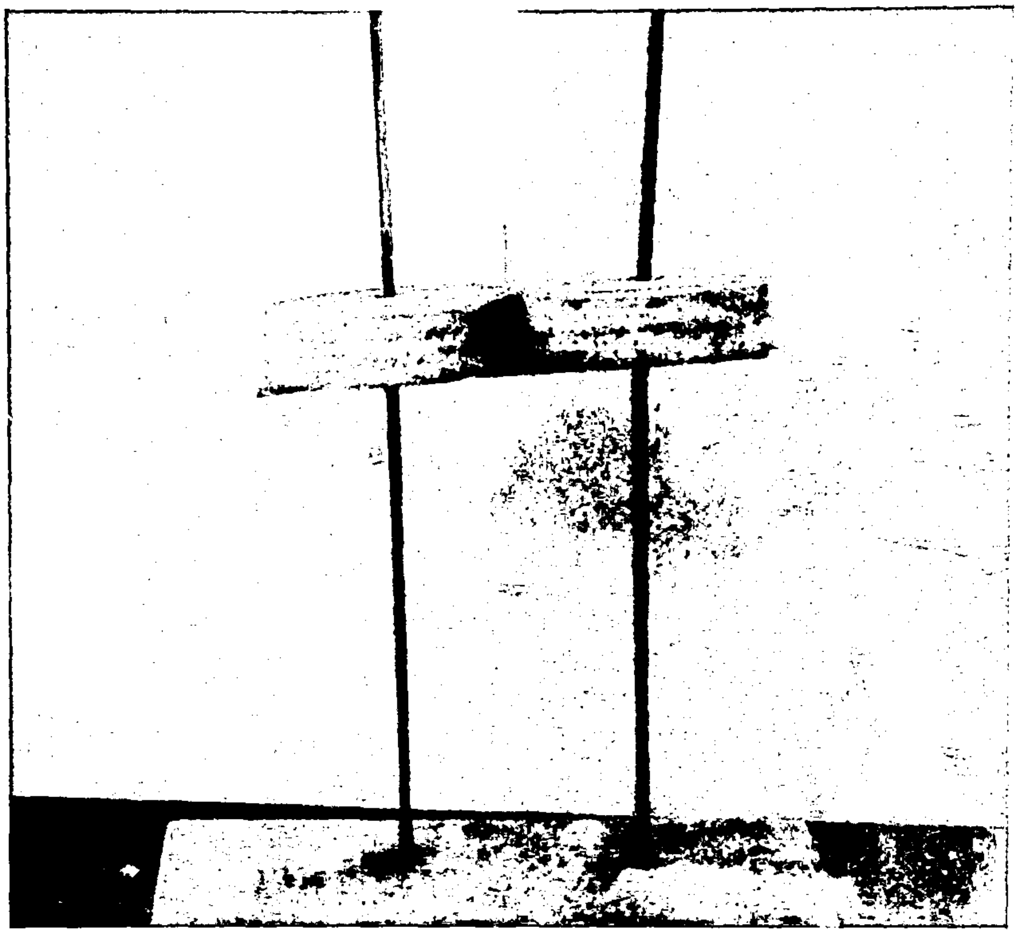
PHOTOGRAPH OF COMBINATION OF THE THREE p-ORBITALS OF A SHELL USED IN THE TEACHING

APPENDIX H



PHOTOGRAPH OF COMBINATION OF THE s-ORBITAL AND THREE p-ORBITALS OF THE L-SHELL USED IN THE TEACHING

APPENDIX I



PHOTOGRAPH OF THE TWO DISCS USED TO DEMONSTRATE

OPPOSITE SPINS OF ELECTRON PAIR IN AN ORBITAL

APPENDIX J

PRETEST SCORES OF STUDENTS IN EACH GROUP

"Diagrams Only" Group (n = 44)		"Models Only" Group (n = 33)		"Diagrams and Models" Group (n = 46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
1	1	1	1	1	4
2	0	2	0	2	2
3	1	3	0	3	3
4	0	4	0	4	1
5	0	5	0	5	4
6	0	6	0	6	1
7	0	7	0	7	2
8	0	8	1	8	2
9	2	9	3	9	4
10	0	10	0	10	2
11	2	11	0	11	3
12	4	12	0	12	2
13	0	13	2	13	2
14	0	14	1	14	4
15	1	15	1	15	3
16	1	16	0	16	4
17	6	17	0	17	4
18	1	18	0	18	4

APPENDIX J CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
19.	0	19.	0	19.	3
20.	1	20.	0	20.	3
21.	2	21.	0	21.	2
22.	1	22.	1	22.	4
23.	1	23.	0	23.	4
24.	2	24.	0	24.	2
25.	0	25.	0	25.	1
26.	0	26.	3	26.	2
27.	0	27.	1	27.	2
28.	0	28.	0	28.	1
29.	1	29.	0	29.	1
30.	0	30.	0	30.	1
31.	1	31.	0	31.	1
32.	0	32.	0	32.	1
33.	0	33.	0	33.	4
34.	0			34.	3
35.	0			35.	2
36.	1			36.	2
37.	1			37.	4
38.	0			38.	3
39.	0			39.	3
40.	0			40.	1
41.	1			41.	1
42.	0			42.	3

APPENDIX J CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
43.	1			43.	4
44.	1			44.	3
				45.	5
				46.	1

Group Mean = 0.75	Group Mean = 0.42	Group Mean = 2.57
Standard Dev = 1.16	Standard Dev = 0.83	Standard Dev = 1.18

APPENDIX K

POSTTEST SCORES OF STUDENTS IN EACH GROUP

"Diagrams Only" Group (n = 44)		"Models Only" Group (n = 33)		"Diagrams and Models" Group (n = 46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
1	0	1	7	1	7
2	1	2	3	2	5
3	5	3	3	3	6
4	4	4	5	4	4
5	4	5	7	5	4
6	2	6	5	6	6
7	0	7	6	7	5
8	3	8	4	8	6
9	5	9	5	9	5
10	4	10	4	10	4
11	5	11	5	11	2
12	3	12	6	12	1
13	0	13	5	13	6
14	0	14	5	14	7
15	1	15	5	15	6
16	4	16	5	16	7
17	4	17	2	17	5
18	4	18	4	18	6

APPENDIX K CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
19.	1	19.	6	19.	6
20.	0	20.	10	20.	9
21.	5	21.	8	21.	8
22.	3	22.	7	22.	5
23.	1	23.	2	23.	5
24.	0	24.	5	24.	6
25.	0	25.	6	25.	6
26.	1	26.	7	26.	5
27.	1	27.	8	27.	7
28.	4	28.	4	28.	5
29.	0	29.	8	29.	7
30.	0	30.	8	30.	4
31.	3	31.	6	31.	6
32.	3	32.	8	32.	4
33.	2	33.	8	33.	5
34.	1			34.	6
35.	3			35.	4
36.	2			36.	7
37.	2			37.	7
38.	1			38.	3
39.	2			39.	4
40.	0			40.	4
41.	1			41.	3
42.	1			42.	5

APPENDIX K CONTD

"Diagrams Only" Croup (n=44)		"Models Only" Group (n=33)		"Diagrams and Models" Group (n=46)	
Student No.	Score Out of 10	Student No.	Score Out of 10	Student No.	Score Out of 10
43.	1			43.	6
44.	2			44.	4
				45.	7
				46.	5

Group Mean = 2.02	Group Mean = 5.67	Group Mean = 5.33
Standard Dev = 1.68	Standard Dev = 1.90	Standard Dev = 1.54