TEACHING AND LEARNING HIGH SCHOOL PHYSICS THROUGH ANALOGIES: A CASE STUDY OF KENYAN CLASSROOMS

by

Samson Madera Nashon

A thesis submitted in conformity with the requirements for the degree of Doctor of Education
Department of Curriculum, Teaching and Learning
Ontario Institute for Studies in Education of the
University of Toronto

© Copyright by Samson Madera Nashon 2001
The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L’auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L’auteur conserve la propriété du droit d’auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.
Teaching and Learning High School Physics Through Analogies:

A Case Study of Kenyan Classrooms

Doctor of Education, 2001

Samson Madera Nashon

Department of Curriculum, Teaching and Learning

University of Toronto

Abstract

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education. Analogy is a widely used instructional tool in science. Because of the many abstract concepts the subject embodies, analogy use is particularly common in physics education.

Findings showed that the analogies were largely environmental (cultural), anthropomorphic and spontaneously generated. There was no evidence to indicate teachers' use of a theoretical model, such as Zeitoun's (1984) General Model for
Analogical Teaching (GMAT), Glynn's (1991) Teaching With Analogies (TWA) or Nashon's (2000) Working With Analogies (WWA) model. It was found that alternative frameworks for some concepts still existed among the students despite the analogical teaching. Some of the frameworks appeared to persist even in the presence of correct information, while others were a consequence of literal interpretation of scientific terms or phrases. The few analogies that students generated for themselves reflected their understanding of analogically taught concepts (Pittman. 1999) and could therefore, to some extent be judged successful. However, some misconceptions were still noticeable.

Findings of this study may have an impact on the way teachers teach science, and, more so, physics – in particular, on the analogies they use. the concepts they teach and the methods they chose to use in teaching the concepts (in general), all of which depend on the context.
**Acknowledgement**

In recognizing those who have facilitated the creation of this thesis, I first wish to acknowledge the invaluable contribution of my supervisor, Professor Derek Hodson. Professor Hodson was involved from the very beginning when I was writing the research proposal. His thoughtful insights guided me in conceptualising this research. I always recalled his sound advice while gathering data in the field. Through his critique during the analysis and writing of this thesis, I not only learned more about my research but I also learned skills which enabled me to critically examine the data corpus from which I made interesting inferences and conclusions. I appreciate also the patience he showed in the extensive copy editing of the chapters in this thesis.

Others were also instrumental in guiding and critiquing this thesis. Professors Erminia Pedretti and Brent Kilbourn, also on my thesis committee, posed challenging questions to the content of the thesis and supported me as I addressed them. They pointed me to useful references which helped me grapple with themes emerging from my thesis.

For all that these three people have done professionally in advising me in my research, my debt to them extends to a personal arena. I find it hard to express how important was all the time, attention and encouragement they offered me. They understood the difficulties in writing a thesis and raising a family. Their support and interest in the welfare of my family is greatly appreciated.

I would not like to end this acknowledgement before I pay my tribute to Professor Clare Kosnik who I had very close working relationship as her Graduate Assistant (GA). She always read my thesis chapters and raised pertinent issues that in most cases required clarification and further development. Although I was a Graduate Assistant under her supervision, she
nevertheless considered me as a colleague and read my thesis chapters with the interest and open
mind that such a piece of work deserves.

Special thanks also go to the Kenyan high school in which I conducted the research. I
particularly would like to thank most sincerely and express my unwavering gratitude to the three
physics teachers and their students for agreeing to participate in my study. Their co-operation
during actual classroom observation and readiness to be interviewed and discuss instructional
issues really made my search for answers to my research questions realised. In another special
way I would also like to acknowledge the unlevelled support accorded to me by the school
Principal, the Deputy Principal, the entire teaching and non-teaching staff who included the
school lab technician. Assigning me to teach one of the physics classes, the Principal in a special
way enhanced my endeavour to conduct a research in an environment in which everybody saw
me as one of their own and whose presence was trusted and appreciated. Furthermore, this
atmosphere facilitated my endeavour to establish good rapport with everybody in the school
community.

This study would not have been possible if it were not for the permission granted by the
office of the President of the Republic of Kenya. I value the trust and freedom accorded to me
during the time of data collection. It is not everybody who applies for a permit to do research that
gets it, therefore I consider this a privilege that I must appreciate.

Concerning this, I thank in a special way my friend Chabala and his family for
accommodating me without charge. The true friendship this family extended to me and the
assured transport to the research school the family provided, made my study a success. I note the
difficult times this family underwent when their beloved son passed away, but still, they never
wavered in their attention to my goal of collecting data in a school several kilometres away from their residence.

My other greatest tribute goes to my daughter Brigid Midika, though very young, spent tireless times typing the thesis chapters into computer. She was always there when I needed her. Of course, my other family members, especially my wife Ebby, who was also a candidate, gave me the co-operation and love that I needed most when my moods were low. I also wish not to underestimate the high level of support I received from my other children, Celestine, Nickson, Patrick and Gary. They were very understanding and caring.

Finally, let me end this acknowledgement by paying special tribute to the University of Toronto through OISE for offering me grants in the form of UTAPS. Graduate Assistantship (GA) and Teaching Education Program Assistantship (TEPA) to supplement the payment of my university fees.

Though unending, I should not forget to acknowledge the knowledge I acquired during my course work, from the professors who taught me and the graduate students with whom I took the courses. In addition, I acknowledge the preservice duties as a TEPA and GA, for they offered me opportune moments to reflect on how the theories I learnt in graduate courses worked in practice. The opportunities availed to me in the course of these duties - to supervise preservice students on the practicum, are quite unforgettable privileges. This presented to me live situations in which I saw what I was writing about come true or get challenged.
## CONTENTS

**Abstract**

**Acknowledgment**

**Chapter One: Introduction**

Purposes of the Study

Research Questions

Rationale for the Study

The Kenyan Context

Context of the Study

Observation Period

Case Study and the Current Research

Researcher Background

Developing Analogies

- Systematic Attribute Mapping
- Systematic Structural Mapping

Analogies, Metaphors, Models and Examples

**Chapter Two: Theoretical framework**

The Meaning of Analogy

Analogies and Metaphors

Analogies and Models

Analogies and Examples

Features of an Analogy

Learning through Analogies

Constructivism and Learning

Conditions for Accommodation

The Process of Conceptual Change

Analogical Learning

Summary
<table>
<thead>
<tr>
<th>Chapter Three: Previous Studies and Problem Statement</th>
<th>57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Studies</td>
<td>57</td>
</tr>
<tr>
<td>Methodological Issues</td>
<td>58</td>
</tr>
<tr>
<td>Categories of Analogies</td>
<td>59</td>
</tr>
<tr>
<td>Teachers’ Use of Analogies</td>
<td>64</td>
</tr>
<tr>
<td>Students’ Use of Analogies and Learning</td>
<td>67</td>
</tr>
<tr>
<td>Analogies as Assessment Tools</td>
<td>79</td>
</tr>
<tr>
<td>Problem Statement and Educational Significance</td>
<td>80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Four: Methodology</th>
<th>83</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Case Study</td>
<td>84</td>
</tr>
<tr>
<td>Methods of Collecting Data</td>
<td>85</td>
</tr>
<tr>
<td>Classroom Observation</td>
<td>87</td>
</tr>
<tr>
<td>Interviewing</td>
<td>91</td>
</tr>
<tr>
<td>Techniques of Recording Data</td>
<td>93</td>
</tr>
<tr>
<td>Trustworthiness/Credibility of Data and Conclusions</td>
<td>94</td>
</tr>
<tr>
<td>Ethical Issues</td>
<td>95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Five: Data and Analysis</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>100</td>
</tr>
<tr>
<td>Data on Analogies</td>
<td>102</td>
</tr>
<tr>
<td>Students’ Alternative Frameworks</td>
<td>120</td>
</tr>
<tr>
<td>Conducting Analysis</td>
<td>123</td>
</tr>
<tr>
<td>Context of the Analogies</td>
<td>126</td>
</tr>
<tr>
<td>WWA Model and the Case Study Analogies</td>
<td>147</td>
</tr>
<tr>
<td>Inferences and Assertions</td>
<td>154</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Six: Discussion</th>
<th>181</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental analogue and Analogies</td>
<td>181</td>
</tr>
<tr>
<td>Anthropomorphism</td>
<td>184</td>
</tr>
<tr>
<td>Nature of Students’ Alternative Frameworks</td>
<td>196</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Advantages of Analogy Use</td>
<td>210</td>
</tr>
<tr>
<td>Disadvantages and Limitations of Analogy Use</td>
<td>213</td>
</tr>
</tbody>
</table>

**Chapter Seven: Suggestions for Teaching and Further Research** 217

- Teaching suggestions 217
- Recommendations for Further research 226
- Study Summary 238
- Limitations of the study 229

**References** 232

**Appendix 1: Ethical Review Protocol** 241

**Appendix 2a: Research Authorisation Letter** 249

**Appendix 2b: Researcher Identification Card** 250

**Appendix 2c: Endorsed Copy of Research Authorisation Letter** 251
Chapter One

Introduction

Analogy use is common in science teaching, and more so in physics. This is because of the many abstract concepts that physics embodies. Analogies are teaching tools that compare structures of two domains by indicating the similarities of the parts of the structures (Duit, 1991).

Everyday use of the term analogy includes metaphors, models and to some extent examples, though there are important differences between these terms. This will be discussed later in this chapter and in chapter two.

Many studies have been done on the “use of analogies” in teaching science concepts. But there are few studies done in Africa, and most of those are in the area of biology (Lagoke, Jegede & Oyebanji, 1997). Furthermore, the Lagoke et al. study was conducted in Nigeria; there have been hardly any studies on the use of analogies in Kenya.

The current high school curriculum in Kenya puts emphasis on science subjects and yet students’ performance in the science subjects in national examinations has been consistently poor over the years. The students, the parents and other stakeholders yearn for good grades in science subjects, because there are still job opportunities in science related fields. Entry into science related courses at universities and middle level colleges require that candidates get good grades in science at high school level. In other words, to get to courses like engineering, medicine, computer science, architecture and agriculture, a student
must get good grades in the sciences (biology, physics, chemistry and physical science) in the Kenya Certificate of Secondary Education (KCSE). KCSE is a national examination that students take after four years of high school education. Performance in this examination determines whether one can get university/college admission or not. This puts pressure on the students as well as the teachers to produce good results. A successful teacher in Kenya is one who produces better results by having many students do well in KCSE and one who has many students joining universities. This teacher is even more recognised and respected by having many of his/her students join the "best" courses at the universities. At present, the "best courses" are science related. This is because with qualification in any of the courses, one is almost certain of getting a job.

Students are required to score highly in physics in order to get admission to what has been referred to as "good" courses (engineering, architecture, medicine, computer science, nursing, agriculture, etc.). Selection of subjects to take for KCSE is done in form two\(^1\) (grade 10). This therefore calls for an

---

\(^1\) Form two (16 year olds) in Kenya is equivalent to grade 10 in the Canadian system and 12 to 13 year olds in the United Kingdom. Children in Kenya start primary school at the age of 7 (grade 1) and join secondary school (Form 1) at 15 years of age – an equivalent of the Canadian grade 9. KCSE is taken at the end of form 4 (18 year olds). This is unlike in the UK where children finish secondary school at the age of 16 with a GCSE certificate, although 16 is the school leaving age. Otherwise, many students stay in school for a further two years and take General Certificate of Education (GCE) A-level exams (major university entrance qualification). However, these ages for the Kenyan classrooms are only minimum requirement but there is no age limit as such. It is not surprising to find much older children in classes where the majority of the children are much younger. In grade 1 or standard 1 children can be as old as 10 years of age.
examination of how the subject is taught and learned prior to the selection. Hence, a need for a detailed study of one of the important teaching tools in physics (use of analogy) on the grounds that better teaching will attract many students to select the subject.

Purposes of the Study

As stated at the beginning of this chapter, physics embodies many abstract concepts. To understand such concepts “good” teaching tools must be employed. One such a “tool” is analogy use. Because of this, a study was conducted to:

(i) Identify the nature of the analogies that form two physics teachers in Kenya use to explain physics concepts;
(ii) Determine and discuss how suitable the analogies are to the Kenyan context; and
(iii) Identify and discuss the effect that these analogies have on students’ conception of analogously taught concepts.

To achieve these purposes, several questions were addressed. However, three key research questions directed this study.

Research Questions

It has already been pointed out that many studies have been conducted on analogy use in teaching science. In the majority of these studies, teachers were provided with single or a group of analogies to use. In contrast, this research was concerned with capturing the analogies that teachers used without being
"coerced" into doing so. Furthermore, most previous studies, as also stated above, were conducted outside the continent of Africa, and the few studies that have been done in Africa (such as Lagoke et al., 1997) have dealt with biological topics. No research in Africa in the area of physics teaching through analogies is documented. This lack of studies in the use of analogies in teaching physics concepts prompted the researcher to identify, determine the nature and examine the suitability of the analogies and the effect they have on the students' understanding of analogously taught concepts to form two physics students in Kenya. While open to empirical analysis, it seems reasonable to suggest that students' understanding of physics concepts is affected partly by badly used analogies, which may contribute to the poor performance in national examinations, a factor that seems to discourage many students from taking physics after form two. As already indicated, studying the way teachers deploy analogies may be one way of addressing this problem. Therefore, it was important that analogies that teachers use be captured in situ and studied. To capture the analogies and their effect on students' conceptions, the following research questions were formulated:

1. What analogies are used?
2. What are their characteristics?
3. What alternative frameworks do students hold after analogous instructions?

The problem here is that:
(i) no research is documented regarding the use of analogies in teaching physics in Kenya, hence denying the teachers and students the knowledge regarding the nature of the analogies they use;

(ii) English language is the medium of instruction and at the same time a second language. This does affect students’ free expression of ideas and even understanding. Teachers may also be victims as well, by lacking the simple alternative vocabulary to understand the concepts they teach them.

Rationale for the Study

Physics is a subject that is given a lot of importance in the Kenyan education system. It is a subject, as already indicated, that guarantees high school graduates a career in science related professions. It is also in these professions that jobs can still be found and yet so many high school graduates fail this subject. However, performance in physics in national schools is better than other types of schools.

The majority of schools in Kenya are in the rural areas, including some national schools. National schools pick their students using the “quarter system of selection”; ensuring rural/urban student portions. More information about national schools and the quarter system of student selection is discussed in chapter four.

The medium of instruction in Kenya, as already indicated, is English - a second
language. Using analogies may be one way of simplifying and economising on the words one has to use in explaining abstract concepts.

Because of language difficulties, analogies, which are common tools for teaching science concepts, are in some cases memorised as facts. Furthermore, lack of studies on analogy use in the African context is a major concern that prompted the researcher to conduct a case study involving three physics classes. In these classes, the researcher spent 14 weeks observing every physics lesson in order to capture, in situ, the analogies used. This study can be described as a case study because of its setting, composition of participants and the fact that the generalisations, conclusions and assertions are only specific to the three classrooms. But, before discussing the case study, it is important that the choice of the location for the study be discussed.

The Kenyan Context

Kenya operates an 8:4:4 system of education, i.e., eight years of primary education, four years of high school and a minimum of four years of university education. At the end of the primary and secondary phases, students take national examinations, Kenya Certificate of Primary Education (KCPE) and Kenya Certificate of Secondary Education (KCSE) respectively. KCSE enables the students to join universities, middle level colleges or polytechnics. Students choose KCSE subjects at the end of form two. This is why, as stated, the researcher was interested in the way form two students are taught physics, since it impacts the choice of the
subjects the students make. All examinations are written in English because it is both an official language of Kenya and the medium of instruction. Use of English as a medium of instruction in Kenya starts from standard² (grade) four up to university, although prior to standard four, it is taught only as a subject. Selection to high school in Kenya depends on a student’s performance in KCPE. This examination is taken at the average age of 14 years, although age varies from region to region. Although there is an effort to make the standard uniform in all high schools, there are still four categories of high schools: National, Provincial, District and Private schools. In addition to performance, national schools base their selection on a quarter system of selection. The quarter is allocated per district using the formula:

\[
\frac{\text{District Population}}{\text{National Population}} \times \text{Total Number of Places in National Schools}
\]

This gives national schools a relative national outlook in terms of ethnic (tribal) composition. Kenyan ethnic communities are spread throughout the country. However, some districts are occupied by more than one ethnic community while other districts are occupied by only one ethnic community. The mix of ethnic communities (tribes) biased the researcher's choice of a national school. All national schools are boarding. Therefore, the school environment becomes the students' environment as well.

². Primary school classes are called standards in Kenya. For example, grade one or a class of seven-year-olds is referred to as standard one, while high school grades are referred to as forms. For example grade ten or class of 15-year-olds is referred to as form two.
Most national schools have relatively good science facilities. The particular school in which the research was done has a long history of having good science facilities and doing well in science examinations at national level. The level of spoken English amongst the students is relatively good. This is because these students come from all parts of the country. Each part has its own language, although some districts may have more than one community, speaking different languages. In some cases, other languages are spread in more than one district. Apart from English, which is an official language of communication and instruction, Swahili is the only other language spoken throughout Kenya and has been declared a national language. Thus, the only way students in this national school can communicate with each other and their teachers is through English. In other words, the school is a community that has its language as part of its culture.

**Context of the Study**

The study took place in three form two (grade10) physics classes in a national school on the outskirts of the city of Nairobi. Given that it is a national school and its student intake is by the quarter system, the school is multi-ethnic (comprises students from various tribes). The quarter is assigned according to district population. Therefore, students selected from urban centres may include Kenyans of Asian and European decent. But, the number of Asian (mainly Indian) or European students is very small. This is because most European and Asian students go to private schools, where in addition to the Kenya curriculum, they
may take GCE subjects to enable them get admission to European (largely British) and Indian Universities. The significance of multiethnic composition dictated the kind of analogies the teachers used, which largely were environmental. Students' own analogies were environmental as well. They displayed their understanding of the analogies and the new concepts or ideas in terms of local experiences. Each class alternated between two places: the laboratory and the classroom.

The researcher's major role was that of a passive observer. However, to ensure that the teachers and the students became familiar and comfortable with his presence, the researcher was assigned one physics class to teach. Of course, this class was not one of those in which the research was taking place. This arrangement was acceptable to all the teaching staff and students because the researcher is an experienced and registered teacher in Kenya, and was supported by the school Principal.

The initial plan was that the researcher would interview the teachers involved in the study and a sampled group of students after every topic, resulting in at least eighteen formal interviews. This idea was abandoned because it seemed to inconvenience the teachers and students. Instead, the researcher found informal interviewing to be productive, especially moments before and after departmental meetings or lessons. Sometimes chatting during recess time proved useful. This was because other members of the science department joined in the discussion and contributed valuable insights. For example, one experienced biology teacher,
a long time examiner in biology, talked of how surprising it was for him to find students in national examinations responding to questions on transportation in plants using analogies.

Because the researcher participated in the day-to-day activities of the entire school and physics department, the teachers in the physics department became supportive. For example, during the classroom observation, it was either the laboratory technician or one of the physics teachers not teaching at the time who video-taped the lessons. The teachers found video-taping valuable and gained useful insight (and enjoyment) from seeing themselves and their classes in action. This was important since it provided them with opportunities to reflect on their performance and that of their students during the teaching and learning interactions. From their reactions, the researcher was able to ascertain their perception of the recordings. Video-taping became an unexpected and very useful additional source of research data on analogies that the teachers used in teaching physics concepts.

**Observation Period**

The study extended over 14 weeks, or one term, with three different teachers in three form two physics classes. The period of 14 weeks of classroom observation was chosen because teachers would usually cover about three to four topics in such a period. This is long enough for a variety of analogies to be utilised by the three teachers in three different classes. Term two in the school
calendar was chosen because it is the longest and is the term in which a lot of teaching takes place.

The researcher ensured that he got to the school before the students came back from vacation, reporting to the school on a Monday while the students reported back from their April vacation on the Thursday of the same week. The timetable was plotted in a way that catered for the researcher’s interests, with no overlapping of the lessons for the researcher and the three teachers involved in the study. The fact that the researcher was on the timetable as a teacher of one of the physics classes, and attended departmental meetings as well as main staff meetings, eased any tension that could have developed amongst the teachers and students. They did not see themselves as being assessed or evaluated by the researcher, a source of many problems for researchers in other situations. Denzin and Lincoln (1998) point out that “...the human status of actors whom we study... have perspectives on and interpretations of their own and other actors’ actions. As researchers, we are required to learn what we can of their interpretations and perspectives” (p.172). This may help the researcher to forge a good rapport with the subjects (teachers and students) involved in the study. However, Denzin and Lincoln, caution that this may not always be an advantage to obtaining reliable data. This is because the researcher might end up being a mouth piece of the subjects and may “... ‘go native’ and become a member of the group . . . [forgetting] the academic role” (p.60), hence losing his/her distance and objectivity. Awareness of this prompted the researcher to ensure that, as the term
progressed, he consulted extensively with all the physics teachers, including those who were participating in the research. The consultation centred on the teachers’ approaches to teaching certain concepts - the kind of laboratory activities they provided, and how they organised such activities. This is a case of “insider” versus “outsider” knowledge. In his review of the book entitled “Inside/outside: Teacher Research and Knowledge” by Cochran-Smith and Lytle (1993), George (1995) points out that the book exposes what academic educational researchers from institutions of higher learning have overlooked for a long time. He states that the book interprets teacher research as “…insider’s knowledge, grounded within the intellectual frameworks and life experiences of teachers, themselves” (p.2), a view that significantly is “…different from that of an outside observer, even if that observer assumes an ethnographic stance and spends considerable time in the classroom” (cited from Cochran-Smith and Lytle, 1993, p.18). In this study, the researcher was the outsider and to get authentic details of what goes on within the labs, classrooms and the school, the insiders were very important. The laboratory technician and the physics teachers all had unique knowledge that only insiders like them could know. Thus, good rapport in this case meant having a relationship with the physics teachers and the lab technician that enabled them to reveal to the researcher useful information that otherwise would not have been made available. Throughout, the researcher enjoyed the advice and co-operation of both the laboratory technician and the teachers. This brought the teachers “closer” and enabled them to regard the researcher as “one of their own”, rather than someone
with “super” knowledge, concerned with scrutinising their good or bad teaching methods.

Kenya has a very strong and relatively effective inspectorate department in the Ministry of Education. It is common to find teachers uncomfortable with the presence of inspectors in their classes. Although the role of inspectors has changed tremendously over the years, the image of harassment and ridicule persists amongst older teachers, who at one time or the other had the worst experiences of these inspectors. Participating fully in school activities and continued discussion with the teachers diminished any fears of assessment and evaluation. Given that their colleagues from other physics classes videotaped for the researcher, these teachers became more confident and trusting of the researcher. They became more revealing and open as the research progressed. An observation by a stranger in another person’s classroom is usually viewed with suspicion of assessment and evaluation. Ball (1988) calls it the “Hawthorne effect”, defined as:

... a reactive effect and it refers to the change in behaviour that occurs when the subjects in an ... experiment are aware that they are being observed ... so any positive improvement in the research can be usually ascribed to the awareness of the subjects. (p.91)

In a case like this, the Hawthorne effect can inhibit the generation of spontaneous analogies the teacher may want to use. It may also hinder students’ eagerness to ask questions or contribute to classroom discussion - another way in which alternative frameworks can be exposed. This may initially have affected students’ active participation, but because of the collective planning and free
discussion of topics and laboratory activities between the researcher and the teachers, the Hawthorne effect appeared minimised. This was evident in the teachers’ spontaneous use of analogies.

This study can be described as a case study. Findings of this case may or may not have relevance to what goes on in other physics classrooms elsewhere in the world. However, the study provides a model of classroom observation that can be conducted by other teachers and teacher researchers in order to understand the teaching tools they use in physics instruction.

Case Study and the Current Research

Before defining what case study is, it is proper to develop briefly the meaning of a case and relate it to the present study. Stake (1978) defines a case as a constituent member of a target population. Here the target population includes all high school physics teachers and their classes. The three teachers and their classes form a case for study, hence case study. According to Yin (1984), a case study is “... an empirical inquiry that investigates a contemporary phenomenon within the real life context ... in which multiple sources of evidence are used” (p.23).

The study was an inquiry into physics classroom settings in which analogies were used. It required the observer to note every analogy used during a series of physics lessons and to ascertain how the teachers related the analogies to new concepts or ideas. Stake (1978) points out that case study is both the process of learning about the case and the product of their learning. In the process of
observation, one can learn from many of the events. For example, in this case, there emerged spontaneously generated and universal analogies, localised analogies and students' alternative frameworks. Merriam (1988), referring to the qualitative nature of most case studies (into which this study also falls), defined qualitative case study as "... an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process, or a social unit" (p.16).

Merriam's definition exemplifies the meaning of case study by giving specific examples. In the context of her definition, this study falls into the category of social units: form two physics classes. From Yin's (1984) and Merriam's (1988) definitions, the study was empirical and holistic since it involved real classroom experiences. Immersion into the physics classrooms for 14 weeks was the approach adopted in gathering information about analogy use in high school physics teaching in Kenya. While observing, leading questions were largely of the "why" and "how" variety. The observation was reflective (Schon, 1983; Stake, 1978), a view which Stake (1978) elaborates as follows:

Local meanings are important; foreshadowed meanings are important; and readers' consequential meanings are important. The case researcher teases out meanings of these three kinds for whatever reason works on one kind more than the others. In each case, the work is reflective. (p.242)

The researcher was open minded during the observation and gave the observations every interpretation possible. However, by engaging in this study, the researcher realised that there were certain major conceptual responsibilities to bear
what Stake (1978) describes as "conceptualising the object of the study". In other words, this meant that the researcher defines clearly the study focus (analogies). Analogies were looked for in various sources, including the teachers, the students, documents and other accessible but relevant materials. This enabled the researcher to select alternative interpretations to pursue. It required the researcher to avoid jumping to conclusions until the end of the study.

Given the fact that every classroom is unique and each researcher has a distinctive point of view, no two or more people researching on the same problem in different (or even the same) classrooms will generate the same findings. This view is reiterated by Erickson (1994):

... in given situations of practical action, humans often seem to have created similar meaning interpretations. But these surface similarities mask an underlying diversity; in a given situation of action one cannot assume that the behaviour of the two individuals, physical acts with similar form, have the same meaning to the two individuals. The possibility is always present that different individuals may have differing interpretations of the meaning of what, in physical form, appear to be the same or similar objects or behaviours. (p.126)

This means that every piece of classroom research significantly contributes to the development of knowledge in a different way. What can be considered a significant contribution of this present research? The answer may partly lie in the fact that every analogy used may significantly have affected the students' way of understanding physics concepts. The area of physics teaching is increasingly receiving a lot of attention from education scholars and administrators because of its (physics) supposed unattractiveness to many students. Kenya is no exception to such problems. This background directed the researcher's interest in observing
three form two physics classes. A study like this cannot claim to be the first, nor
the last; rather, it was undertaken in the context of other existing studies, some of
which have been discussed in chapter three.

Below is the background information about the researcher. This
information helps the reader in appreciating why the researcher considered this
study very important.

**Researcher Background**

The researcher has long experience with physics instruction. This
experience comes from: first, as a physics student throughout his education from
secondary to undergraduate level; second, as a high school physics teacher, a
teacher trainer, a science editor and a moderator and examiner of physics
examinations. Most of his experiences have been with curriculum design,
implementation and evaluation. In addition, the researcher has authored several
curriculum related mathematics books; a subject that has much in common with
physics. His last job as a science editor was even more challenging, editing
science materials (physics books included) for use in Kenyan classrooms.

His firsthand experience with the classroom, syllabus, examinations and
teacher education enabled him to successfully chair various panels of authors of
both primary science and high school physics books. Through all these
experiences, the researcher came to realise that analogies are powerful tools in
physics, especially when used carefully and appropriately.
The long extensive experience the researcher has had in physics-related subjects confirm cautionary notes that if analogies are not carefully constructed, they can lead to misconceptions (Black & Solomon, 1987; Stavy, 1991; Webb, 1985; Zeitoun, 1984). In other words, wrong messages can be sent to learners, teachers and those others associated with curriculum related activities. It is anticipated that the findings in this study will contribute to quality curriculum development, improved evaluation processes and better physics teacher education, both in Kenya and elsewhere. It is this background that gave the researcher the desire to find out what analogies Kenyan teachers use in explaining physics concepts and whether the analogies do what they are intended to do. To understand the analogies that teachers use, it is important to have general information on how good analogies are developed. This information is discussed below.

**Developing Analogies**

In focusing on the nature of analogies, the context in which they are developed or generated is important. Analogies that have a cultural sense are referred to as environmental analogies (Lagoke, Jegede & Oyebanji, 1997). Environmental (cultural) analogies have been found to work well, as evidenced in the Lagoke et al. study:

... there is a need to harness all the beneficial aspects of our culture to make science more accessible to African children. (Jegede & Okebukola, 1989 in Lagoke et al., 1997, p.368);
(...): boys and girls benefit significantly from teachings with environmental analogies when compared with their counterparts...not similarly taught ... (Lagoke, et al., 1997, p.376)

Environmental analogies, like all other analogies, must be constructed systematically (Gentner, 1983) by comparing two similar domains or paradigms in order to have a more positive effect on teaching and learning of science concepts. Systematic comparison is about attribute matching or mismatching in the domains that constitute an analogy – analogue (familiar concept/situation) and target (unfamiliar concept or concept to be explained) (Gentner, 1983; Glynn, 1991; Harrison & Treagust, 1994; Zeitoun, 1984).

In addition, systematic development of an analogy is incomplete if it is not based on some kind of theoretical model. Such models include Glynn’s (1991) Teaching With Analogy (TWA), Nashon’s (2000) Working With Analogies (WWA) and Zeitoun’s (1984) General Model for Analogical Teaching (GMAT). Details of these models are discussed in chapter two.

Because of the importance of attribute mapping in an analogy, it is important that some brief explanation of what is involved be provided. Below are brief explanations of two kinds of mapping in an analogical comparison.

**Systematic Attribute Mapping**

Systematic attribute mapping matches features of the analogue with features of the target. In an analogy, relations have priority over object attributes (Gentner, 1983).
Part of our understanding about analogy is that it conveys a system of connected knowledge, not a mere assortment of independent facts. Such a system can be represented by interconnected predicate structure in which higher order predicates enforce connections among lower-order predicates. (p.162)

Attributes, therefore, are predicates (what is said about the subject) that take one argument, whereas relations take two or more arguments. Some of the analogies in chapter four are "attributal" in nature and the rest are relational. Relational analogies in the study were holistically used. When holistically applied, the effect of the mismatches on the understanding of new concepts is missed. This contributes to the development of misconceptions.

**Systematic Structural Mapping**

In structural mapping a distinction which is simple but powerful is made among predicate types (Gentner, 1983). These predicate types allow the statement of "which [attributes] are mapped and which are not". A complete analogy should explicitly display two types of attributes or predicates: similar (mapped) or dissimilar (unmapped or irrelevant) (Gentner, 1983; Glynn, 1991; Harrison & Treagust, 1993; Zeitoun, 1984).

The important idea in an analogy is the fact that a relational structure that normally applies in one domain can be applied to another domain (Gentner, 1983). Gentner has indicated how studies in scientific learning and reasoning have emphasised the importance of representational structures:

... much of the psychological experimentation on analogy... has been ... based on rather simple representations of meaning (...) These kinds of
representations can deal well with object attributes, but are extremely limited in their ability to express relations between objects ... (p.166)

This quotation reveals another purpose of analogies, that of mapping relations in conceptual structures in different domains. According to Gentner (1983), potential analogies are less likely to be noticed since they require accessing the data via relational matches. However, once found, “an analogy should be more useful in deriving the key principles since the shared data structure is sparse enough to permit analysis” (Gentner, 1983, p. 168).

Analogies greatly increase the rate of learning and can make learning and retention possible. According to Lawson and Lawson (1993), “Analogies can greatly facilitate learning and retention because they activate the outstars (... the cells that use sampling the to-be-learned pattern) ... and cause the neural activity to grow exponentially by forming feedback loops” (p.1327). This has led to the prevalent use of analogies in teaching those science subjects that contain abstract concepts. In view of this, analogy use becomes a tool in teaching and, more so, in teaching science subjects - physics taking the lead.

This unique character of physics teaching prompted the researcher to seek to understand the way physics is taught in Kenyan high schools by focusing on the analogies used by physics teachers.

Before proceeding to chapter two, it is important that distinctions among analogies, metaphors, models and examples be briefly stated. This will enable the reader to have a clear picture of the relevant data in this study. More details about these terms are provided and discussed in chapter two.
Analogies, Metaphors, Models and Examples

As was stated earlier in this chapter, the terms analogy, metaphor, model and example are sometimes used interchangeably. However, there are distinct technical differences.

In brief, an analogy explicitly compares structures between two similar domains (Duit, 1991; Glynn, 1991; Nashon, 2000; Zeitoun, 1984). On the other hand, a metaphor implicitly compares structures in two domains (concepts) (Duit, 19991). According to Duit, grounds for comparison in a metaphor are hidden, and taking metaphors literally, renders them false. Nevertheless, there are those metaphors that display characteristics of an analogy and in this study, they have been considered as analogies.

Viewed within the framework of [an analogy] one could say that a metaphor points out some major dissimilarities in order to incite the mind to search for similarities. (Duit, 1994, p.651)

The case is different for models. A model is a representation of a concept or object. From the model, details about the mother concept or object can be obtained. For a model to qualify as an analogy, it must be seen to compare two concepts in different paradigms (Duit, 1991; Kuhn, 1970), e.g, using the solar system model to explain the atomic structure (Bohr) model constitutes an analogy. However, seen from another perspective, this structure of comparing constitutes a model.
When examples are given to portray the characteristics of a concept, they are considered to be in analogical relation (Duit, 1991). Otherwise and ordinarily, examples are different from analogies, since they are instances that justify concepts.

In this study, the term analogy will be used to describe a situation where familiar concepts are used to explain unfamiliar but similar concepts. In other words, the relation may be metaphorical, model-like or example-like, but the key feature is the use of familiar concepts to explain unfamiliar but similar concepts.

The following chapter provides a theoretical framework by discussing in detail the meaning of analogy and the differences between analogies and metaphors, models, and examples. The structure of analogies and their application to analogical and constructivist teaching and learning are also discussed.
Chapter Two

Theoretical Framework

This chapter establishes a theoretical framework in which the study findings are analysed and interpreted. The meaning of analogy, metaphor, model and example, and how they are related, will be discussed in detail. In addition, Piagetian Schema theories and social constructivist ideas in learning will be discussed as well. Three theoretical models for developing an analogy—GMAT, TWA and WWA—are also discussed.

The Meaning of Analogy

Explaining new concepts using similar known and familiar concepts constitutes an analogy. The new concepts are the unfamiliar topics or ideas and the known concepts are the familiar topics or ideas. Therefore, use of familiar ideas, models, situations and maps to explain the unfamiliar constitutes an analogy as well (Black & Solomon, 1987; Duit, 1991; Stepich & Newby, 1988; Thiele & Treagust, 1994; Weller, 1970; Zeitoun, 1984). The familiar concepts (ideas, models, situations and maps) are called analogues or bases and the unfamiliar concepts are called targets or topics (Glynn, 1991; Lagoke et al, 1997; Harrison & Treagust, 1994; Lagoke, 1997; Zeitoun, 1984).

The actual analogy involves comparison of features of both the analogue and the target. These features are sometimes referred to as attributes (Glynn, 1991; Harrison & Treagust, 1994; Zeitoun, 1984). An analogy is complete if
attributes in the analogue match those in the corresponding target. Such attributes are said to be similar; it is these similarities that give the analogy its power. However, in practice not all the attributes in the two domains of the analogy match or are similar.

Stretching further the range of characteristics of an analogy includes relating abstract ideas to the real world and in some cases involves opening new points of view or perspectives (Brown & Clement, 1989; Treagust et al., 1992). In addition, analogies promote visualisation of the abstract and the unfamiliar. In other words, analogies make the invisible and abstract appear visible and real. For example, the familiar water circuit analogy assists mental visualisation of the behaviour of electric current in a circuit by using the behaviour of water in a water circuit. Water represents current. Zeitoun (1984) sums up the meaning of an analogy by saying that “[when] … used as a teaching strategy, [an] analogy provides a comparison, which can explain something difficult to understand by pointing out its similarities to something easy …” (p. 107). This view has also been expressed by Kilbourn (in press) who says, "… helpful analogies tend to be less complex than the phenomena they are meant to depict"(p.3). In other words, analogies have to be simple and meaningful.

In a teaching situation, some analogies are planned in advance of instruction while others are spontaneously generated during instruction. Moreover, some of these analogies are universal while others are local. For the purpose of this discussion, universal analogies refer to those found in textbooks and widely
understood across different social and cultural contexts, while local analogies
apply to those analogies drawn from students’ immediate environment. They are
understood only within the immediate teaching/learning context. Lagoke et al.
(1997) refer to such analogues as “environmental”, in the sense that they are
analogues drawn from the socio-cultural environment of the learner.

Whether planned or spontaneously generated, universal or local, analogies
that teachers use tend to work well. However, there are times when analogies
convey to students wrong meanings of the new concepts (targets), as revealed
during their contribution to classroom or group discussions, or their responses to
test questions on analogous concepts (Gunstone, 1994; Kelly, 1955). Therefore, it
is important to have good research data on the effective use of analogies and to
identify any commonly used analogies that do not function well. This is because
the repertoire of good analogies that teachers and textbooks possess is inadequate

Science is an immensely creative and enriching experience; and it is
full of novelty and exploration; and it is in order to get to these that
analogy is an indispensable instrument. Even analysis, even ability to
plan experiments, even the ability to sort things out and pick them
apart presupposes a good deal of structure, and that structure is
characteristically an analogical one. (p. 479)

To emphasise further how important analogies are, Lagoke et al. (1997) says:

The use of analogy has been found to be beneficial in science learning
by motivating students, providing visualisation of abstract concepts,
providing a basis for comparing similarities of students’ worldviews
with new concepts, promoting associations with other experiences,
overcoming misconceptions, and coping in the classroom with the
complexity of students’ beliefs. (p. 365)
Analogy use is usually prompted by the realisation that some students often lack background knowledge to learn some difficult and unfamiliar topics, such as the atom, Ohm's law and living cells. Zeitoun (1984) has suggested the use of analogies as an interpretative bridge between the unfamiliar science topics (targets) and the knowledge which the students have.

In an analogy, an explicit comparison of the structures of two domains is done. The comparison indicates the identity of parts of the structures in the two domains - analogue and target. Good analogies point out relations between attributes in the two domains. These relationships should be identical. For example, the analogous relationship between electrostatic force, $F_e$, between two-point charges, $q_1$ and $q_2$, a distance, $r$, apart and gravitational force, $F_g$, between two point masses, $m_1$ and $m_2$, a distance, $r$, apart, is symmetrical, i.e.,

$$F_e = k \frac{q_1 q_2}{r^2} \iff F_g = G \frac{m_1 m_2}{r^2},$$

where, $k$ and $G$ are constants.

(Gentner & Gentner, 1983):

A symmetrical mapping can be made between these two expressions:

$$F_e \rightarrow F_g; k \rightarrow G; q_1 \rightarrow m_1; q_2 \rightarrow m_2; r \rightarrow r.$$ 

This is what is meant by identity of structure of the two domains.

It is hoped that at this point the reader has developed a full picture of what analogies are. Everyday use of the term analogy, as seen in chapter one, includes metaphors, models and examples. With the understanding of what an analogy is, it is important to clarify further the important distinctions among analogies, metaphors, models and examples.
Analogies and Metaphors

Analogy and metaphors are "teaching devices" close in meaning and can easily be confused. Both analogies and metaphors express comparisons and highlight similarities. However, their difference is located in the process of comparing (Duit, 1991). An analogy compares the structures of two domains (analogue and target) explicitly by pointing out the identity of parts of the structures, while a metaphor compares without explicitly pointing out the identity. In addition, metaphors often use literary representations or poetic imagery; while analogies operate at a much more analytical level. The apparent essence of a metaphor is to hide the grounds of comparison. A metaphor compares implicitly, highlighting features or relational qualities that do not coincide in the domains. Taken literally, metaphors are plainly false. "Viewed with the framework of [analogy] one could say that a metaphor points out some major dissimilarities in order to incite the mind to search for similarities" (Duit, 1991, p. 651; see also Ortony, 1979, pp. 174 - 175).

In conclusion, analogies can be seen as metaphors and metaphors as analogies (Duit, 1991). For example, a person who takes care of a given family - being responsible for the feeding, dressing and the welfare of the entire family is metaphorically the engine behind the family. This metaphor can be used to explain the functioning of the car engine or any machine engine. Knowing what he/she does in managing family affairs and keeping the family together, and matching with similar functions of a car engine, makes this metaphor an analogy.
Analogies and Models

Under special circumstances models provide analogies (Duit, 1991). Ordinarily, a model is a representation in simple form or simplified description of a system or an idea. There are various types of models, including (i) three dimensional physical representations of objects, examination of which can ascertain facts about the objects they represent, and (ii) theoretical models which are descriptions of ideas (Achinstein, 1968). Although widely used in all sciences, representational models are particularly important in engineering (Achinstein, 1968). Instead of investigating the object directly, engineers may construct a representation of it, called a prototype, which can be studied more readily and under more controlled circumstances than the real thing.

The analogue model is very important in science teaching, especially in physics. The characteristics of the prototype, which mirror those of the mother object, are not themselves reproduced. Instead, an analogy is drawn between two essentially unlike objects or systems, say X and Y, where Y represents X as its analogue and Y is the model of X (Achinstein, 1968). For Y to be the model of X, Y should be treated as something to be studied, for example, the analogy between an electric field and an incompressible fluid that flows through tubes of variable cross sections.

In general, to speak of a model is to talk about something intended to represent a prototype, and in such a way that facts about the prototype can be ascertained by studying, making calculations with respect to, and experimenting upon the model (Achinstein, 1968). Whereas a prototype has to be built, a model analogue needs not. It needs only to be described.
Theoretical models, which are sets of assumptions about X, include the billiard ball model of a gas, which postulates that the molecules comprising a gas exert no forces on each other except on impact (Achinstein, 1968). Once energised, billiard balls travel in straight lines except at the instant of collision, and are very small in size compared to intermolecular distances. Other examples of models include:

(i) the Bohr model of the atom - in this model, an electron revolves round the nucleus of an atom such that its orbital angular momentum is quantised, as is the energy radiated or absorbed by the atom;

(ii) the Corpuscular model of light - in this model, light is considered to comprise particles in motion;

(iii) the shell model of the atomic nucleus - particles in the atomic nucleus are arranged in shells. They move in orbits with quantised angular momentum in a nuclear field created by the particles in the nucleus. This model represents nuclear atomic structures. It is based on the assumption that the number of each kind of the particles (protons and neutrons) contained in each shell is given by \(2(2l+1)\). The orbital angular momentum of particles in each shell is \(lh/2\), (Where \(l\) = angular momentum and \(h\) = Plank’s constant); and

(iv) the free electron model of metals - the valence electrons in the atoms of a metal move freely through the volume of the specimen (Achinstein, 1968).
All these are examples of theoretical models. However, if a model can be used to explain unfamiliar (or new) but similar information, it becomes an analogue model. For example, the Bohr atomic model can be explained using the solar planetary model. Therefore, the solar planetary model is an analogue model. In other words, models may not necessarily explain the target concept but can simplify it for the purpose of explaining through an analogy. The Bohr-Rutherford atomic model does not explain how the electrons and the nucleus function; rather, it simplifies their arrangement for explaining. To explain how electrons move and how they are held in positions, another model - the solar planetary model is used. The planetary model attributes or features include the sun, the planets, and the orbits (Brown, 1972). Matching similar attributes and identifying dissimilar attributes in both models constitutes a complete analogy.

In this analogy, the sun corresponds to the nucleus of the atom, the planets correspond to the electrons of the atom and the orbits of the planets round the sun correspond to the paths that electrons follow (orbitals). However, there are also attributes in both models that are irrelevant. For this analogy to be complete the irrelevant (dissimilar) attributes have to be identified. Dissimilar attributes include the moons, moons’ orbits round the planets, what is inside the sun (e.g. burning hydrogen and helium gases) and the neutrons and protons in the nucleus of the atom. Although this is an oversimplified analogy, it nevertheless provides us with an example of an analogy in which an analogue model (the solar planetary model) is used to explain the target model (the Bohr-Rutherford atomic model).
On the other hand a model can be used as an analogy by itself. For example, kinetic theory, which explains the phenomena of heat and pressure as due to the motion and elastic collision of atoms and molecules, is illustrated by having a glass container with billiard\(^3\) balls. When heat is applied, the balls (small spheres) are seen to move randomly, colliding with each other and with the walls. Their motion increases with increase in heat supply. This arrangement is a model of what happens when heat is applied to a gas in a container - known as the “billiard ball model of gas”. At the same time, the set-up is an analogy. As a model, it represents the (invisible) increase in motion of molecules and atoms and their collision with each other and the walls of the container. As an analogy, billiard balls are regarded as similar to atoms or molecules, and their randomness as similar to that of molecules, say, in a tyre tube. In other words, when a phenomenon is illustrated using a model, which at the same time explains the phenomenon, then that model becomes an analogy.

A model may provide an analogy on condition that the model, which is used to explain some new concept (target), is not in the same domain as the new concept. Furthermore, the two should not be identical. For example, using the drawing of a cow's eye to explain a human eye is not an analogy; nor is drawing the model of

\(3\). Although billiard balls are used, the effect is not as pronounced compared to using polystrene spheres. This is because billiard balls are heavy. Therefore, for effective demonstration, polystrene spheres can be used because they are lighter. However, billiard balls can still be used, as long as their size is smaller compared to the average intermolecular distances, because they have an advantage over glass in relation to their heat capacity: billiard balls have a lower heat capacity than polystrene spheres.
the solar system to explain the actual solar system. But, if the planetary model of
the solar system is used to explain atomic structure, the relation between the two
is analogous because the planetary and atomic structure models are in two
different domains or paradigms (Kuhn, 1970). Therefore, the analogue and target
are different worlds, domains or paradigms whose functioning is perceived as
similar.

This section has discussed the distinction between an analogy and a
model. It has also discussed models as analogues and models as analogies. The
exceptions are the few instances mentioned above when a model serves dual
purposes of analogy and model. Conditions for this have been made clear through
the examples discussed above. The next section discusses the relationship
between analogies and examples.

**Analogies and Examples**

Analogies and examples serve similar purposes insofar as they are used to
make the unfamiliar familiar. However, examples differ from analogies in terms
of usage. An example is an instance of a concept (Duit, 1991; Glynn, 1991), with
the example serving to clarify the concept by making reference to familiar objects
or phenomena. Take, for example, a machine. A machine makes work easier. To
make this definition clearer, an instance is necessary. Such may include a
wheelbarrow, a hammer, or a tractor. All these are machines. They are examples
of machines, but they are not analogies. However, examples can be used as
analogues in analogies. For example, one analogous situation can be used to explain an unfamiliar analogous relationship, such as the family head and the car engine relationship being used as an example in explaining how the heart works.

The cases of metaphors as analogies, models as analogies and examples as analogies are rare situations. Ordinarily, analogies, metaphors, models and examples are different teaching devices used to clarify, simplify or explain complex and new concepts or material. The aim of using such devices is to bring about the understanding of target material or concepts. The next section discusses the features of an analogy. Careful attention to these features is very important when constructing and using an analogy.

Features of an analogy

As stated earlier, an analogy is a teaching/learning device that uses familiar material to explain unfamiliar material or to make abstract knowledge more concrete. An analogy is constituted only when the analogue and target share attributes or have attributes in common. Common or similar attributes are known as *analogous attributes* (Zeitoun, 1984). Of course, part of the nature of analogy is that it may also contain dissimilar attributes or what Zeitoun (1984) calls *irrelevant attributes*. How powerful an analogy is depends on the relative number of similarities compared to the number of dissimilarities in analogue and target domains (Weller, 1970).

**Analogous Attributes**

Attributes are analogous when they exhibit:

(a) Structural similarity, i.e., they look similar or are arranged in a similar configuration;
(b) Functional similarity, i.e., they act in a similar way and;

(c) Consequential similarity, i.e., a similar or same underlying cause creates similar effects (Zeitoun, 1984).

An analogy may have some or all of these characteristics. For example, the atom- solar system analogy has all the three characteristics. Quoting Pollard (1978), Zeitoun shows how the atom and the solar system have structural (physical) similarities because they both are comprised of smaller spheres orbiting larger spheres. They also have functional similarities - smaller spheres spin on axes. And both have consequential similarities since the electric force and gravity are viewed as similar causes that have effects. In addition, the electric force and gravity are similar because they both vary inversely with the square of the distance between their respective sources. However, analogies can be misunderstood and as a consequence may lead to the development of misconceptions among the learners. Stavy (1991) even warns of the resistant nature of misconceptions or preconceptions to ordinary classroom teaching. She advises that “... if students are to change their ideas, they must first feel that their existing conceptions are unsatisfactory in a way” (p. 365). In most cases students are only shown the similar attributes. As a result, students’ preconceptions tend to be dominated by misconceptions (Stavy, 1991).

Teaching to some extent develops by building on students’ correct intuitive preconceptions. Therefore, it is important that teachers look for the students’ correct preconceptions rather than the incorrect. In other words, a good effective analogy has to utilise a correctly understood concept that the student already has. Personal participation of students in developing and understanding such knowledge inculcates a sense of responsibility and ownership by the learners.
(Polanyi, 1962). This view finds favour in Stavy’s (1991) acknowledgement of the influence perceptual elements have in the support for correct intuitive knowledge, and in encouraging transfer by analogy from understanding of known cases to similar cases in the unknown. Thus, there should be at least one analogous attribute between the target (topic) and analogue, otherwise the term analogy may not apply (Zeitoun, 1984).

The correct knowledge that the students already have should constitute the analogue. If the analogue is not well understood by the students, then it must be taught before being used to explain the target. For example, in the familiar camera-eye analogy, knowledge of the camera is used to explain the functioning of the eye. Thus, the eye constitutes the target while the camera is the analogue. Knowing the main parts of the camera and how they function, helps in explaining and visualising how the eye works. Of course, some parts of the eye have to be visualised because they are not directly visible to the learner. Before the analogy is constituted, features of the analogue and the target must be identified. This is then followed by matching similar attributes in the two domains. In this case, matching attributes in the camera and eye domains should be identified as shown below:

*Features of the Camera*

1. The focusing ring - alters the distance of the lens from the film.
2. The lens - focuses the image on the film.
3. The diaphragm - controls the amount of object light entering the camera.
4. The shutter - allows in light or shuts out light from the camera.
5. The spool – revolves as the film winds on it after every snap shot.
6. The film - receives the image of object.

7. The light-tight box - houses the camera parts (gives shape to the camera)
   These attributes of the camera can be identified visually and their functioning
demonstrated practically, both individually and in conjunction.

Features of the Eye
1. The sclera - acts as outer skin to maintain the shape of the eye.
2. The cornea - does the reflecting of light for the lens to focus sharply.
3. The pupil - determines the amount of light entering the eye.
4. The ciliary muscles - adjusts the thickness and curvature of the lens, which
determine the focal length.
5. The iris - automatically adjusts the size of the pupil.
6. The lens - focuses the image of the object on the retina.
7. Aqueous humour - clear fluid in the eye between the lens and cornea.
8. The retina - screen of the eye on which the image is formed.
9. The optic nerve - conducts electric impulses from the retina to the brain.
10. The blind spot - point at which the optic nerve leaves the eye.
11. Vitreous humour - transparent jelly-like tissue filling the eyeball.
12. The eyelid - the upper or lower fold of skin, closing to cover the eye.

Since some of these features (attributes) of the eye are not directly visible, a
part of the camera that operates in a similar manner can be used to explain them. It
follows that, before this analogy is used, it is important to ascertain that the simple
camera is understood well. Features that have similar functions in both the camera
and the eye domains should be identified and matched first:
1. The light-tight box for the camera and the sclera for the eye.
2. The shutter for the camera and the eyelid for the eye.
3. The diaphragm for the camera and the pupil for the eye.
4. The focusing ring for the camera and the ciliary muscles for the eye.
5. The film for the camera and the retina for the eye.
6. The diaphragm adjusting ring for the camera and the iris for the eye.

Although this list does not have all the similar features in the camera and eye domains, it is probably sufficient to help students understand the working of the corresponding parts of the eye. It helps the students to visualise the "activities" in the normal eye. However, the analogy is incomplete if the dissimilar parts between the camera and the eye are ignored. The dissimilar parts are those that are unmatched; they may be extra features the analogue has over the target or *vice versa*. Unmatched attributes in the camera include the spool; unmatched attributes in the eye include the aqueous humour, the vitreous humour, the optic nerve and the blind spot.

In the camera-eye analogy, the unmatched parts of the eye are not explained easily. Indeed, they may each require another analogy in order to explain them. For example, the blind spot and optic nerve may be explained by comparing them to the photovoltaic cell that converts light into electric current.

Sometimes it is important to be careful not to confuse similarity with sameness. Attributes that are the same are not analogous. Zeitoun (1984) explains this by saying:

The term analogy is not applicable when the attributes of the topic [(target)] and the analogue are identical (as is the case of one human eye and the other) or literally similar (as in the case of a human eye and the eye of another mammalia, e.g. rabbit). (p. 109)
Zeitoun states that the term analogy only applies when the target and analogue belong to different schemata (plural of schema). Schema is a term used by Piaget to describe the general knowledge possessed about a particular domain (Stepich & Newby, 1988; Zeitoun, 1984). For example, in the camera-eye analogy, the human eye belongs to the eye schema whereas the camera belongs to the camera schema. Thus, the two schemata are not identical or literally similar. But they are analogically related (Zeitoun, 1984). When pictures, physical models and other illustrations belong to the same schema as the target, they are not considered analogous (Zeitoun, 1991). The term analogy does not apply when a physical model is used to explain the working of the target in the same schema. Thus, the picture of an object is not the analogue of the object when it is used as a teaching aid to explain the object because both the object and the picture belong to the same schema. Learning through analogies is therefore explained by schema theories.

Learning Through Analogies

Schema theories constitute paradigms that can explain certain aspects of learning through analogies. A paradigm is the thinking or framework that guides observation, interpretation and explanation of phenomena or data (Klemke et al., 1998; Kuhn, 1970; Mautner, 1997; Zeitoun, 1984). However, interpretation of data is central to understanding of a paradigm (Kuhn, 1970). Thus, paradigms become what were earlier referred to as “domains” in an analogy. An analogy therefore consists of a comparison of two different paradigms or ‘worlds’. According to Zeitoun (1984), analogical learning is effective when the subject transfers the analogous attributes from the analogue schema to that of the target.
On how effective teaching of science should proceed, Hodson and Reid (1988) advocate the teaching of some theory before providing the students with the practical experiences. Teaching theory first provides the learners and the teacher with opportunities to theorise and explore students' already existing ideas. In other words, practical investigations should be theory-driven - in the sense that practical investigations are used to explore, test and develop students' ideas (or the ideas teachers are trying to persuade the students to adopt). Furthermore, according to Hodson & Reid (1988),

It is not that children frequently do not have the necessary and appropriate theoretical framework, but they have a different one. So they may look in the 'wrong' place in the 'wrong' way and make 'wrong' interpretations. As a consequence they may go through the entire lesson without ever appreciating the point of the experiment, the procedure or the findings. (p.161)

This quotation may be taken to suggest that children have ideas that may be different from the scientifically "correct" ones (accepted ideas or concepts). The aim of teaching is to help children appreciate the "correct" view of science and probably make a shift from the "wrong" ideas (misconceptions or alternative frameworks) to the "correct" ideas. The two sets of ideas are based on two different paradigms: the individual students' paradigms and the teacher's paradigm.

In an attempt to assist these children to undergo a paradigm shift, the new ideas and the methods of developing the new ideas must be plausible, intelligible and fruitful (Hewson & Thorley, 1989; Posner et al., 1982). Once the ideas the students already hold have changed to acceptable ones, the students can use them to explain new concepts. These new ideas thus become a student's preconceptions from which analogues for analogies can be selected. However, a paradigm shift
can be brought about by faulty preconceptions. Therefore, on the one hand, an analogue with no errors ensures transfer of correct ideas from the analogue paradigm to the target paradigm. On the other hand, a misconception in the analogue will be transferred to the target leading to wrong paradigm shift. Therefore, the analogue should contain “correct” science in order to explain the target “correctly”.

Analogical Learning is also effective when the subject isolates the irrelevant attributes of the analogue schema from that of the target schema. Duit (1991) quoting Kelly (1955), exemplifies this point by saying:

Learning is . . . but a process of actively employing the already familiar to understand the unfamiliar. Learning, therefore, fundamentally has to do with constructing similarities between new and already known. It is precisely this aspect that emphasises the significance of analogies in a constructivist learning approach. (p. 652)

**Constructivism and Learning**

Advocates of constructivism argue that knowledge is constructed as the learner interacts with experience(s) (Driver, 1983; Driver & Erickson, 1983; Driver, 1989; Kelly, 1955). Understanding and interpretation of new experiences is dependent on the knowledge the learner already has (Ausubel, 1963; Driver, 1983; Hewson & Thorley, 1989; Hodson, 1998; Matthews, 1994; Posner et al., 1982).

Through analogical experience, learners are expected to **assimilate** or **accommodate** target information – Piagetian terms that describe different modes of learning. The process of assimilation takes place when the new concept or information does not conflict with what the learner already has (Posner, et al., 1982). Such information is accepted easily. However, this is not always the case.
Sometimes the student’s current concepts are inadequate to enable him/her to grasp the new information successfully. Other times the new information conflicts with the student’s current concepts. The student is then forced to reorganise or replace his/her central concepts (Posner et al., 1982). This is called accommodation (Hewson & Thorley, 1989; Posner et al., 1982). According to Posner et al. (1982), the conceptual change model of learning is about the relative status of the existing and the incoming-new information. For a concept to be accepted by the learner its status must be raised and the old idea about the target is lowered in status. In this situation, the new idea is accommodated: the old is replaced by the new, the new idea/concept/information is modified consistent with the old, or the old framework (idea) is reorganised to embrace the new. But, if the old is as good as the new, such that the learner finds both useful, then the new idea gets assimilated. In these two scenarios, the learner undergoes conceptual change (Hewson & Thorley, 1989; Posner, et al, 1982). What this means is that the learner has added new information to what he/she already had or has changed his/her original viewpoint. In other words, the learner now sees things differently, hence the idea of conceptual change.

**Conditions for Accommodation**

Accommodation of target information may take place if:

- The learner is dissatisfied with the existing conceptions or there is a conflict between what the learner already knows and the new information;
- the new concept is more intelligible, i.e., it makes more sense than what the learner already knows;
the new concept is plausible consistent with some aspects of the learner’s existing understanding or preconceptions; and
- the new concept has the potential of being fruitful or useful (Hewson & Thorley, 1989; Hodson, 1998; Posner et al., 1982).

In this context, the purpose of analogy use would be to raise the status of target information so that the learner may see it as intelligible, plausible and useful, or has potential for future use. Consequently, effective analogues may be selected from the knowledge that learners already have. Furthermore, the student should be dissatisfied with the knowledge he/she already has and that the match between analogue and target attributes be systematically done. In addition, the transfer of meaning from the analogue domain to the target domain should satisfy the conditions of intelligibility, plausibility and fruitfulness for the learner to undergo successful conceptual change or paradigm shift.

**The Process of Conceptual Change**

Learning (conceptual change) is brought about from a state of disequilibrium or dissatisfaction. An external experience or an encounter with experiences brings this about. Disequilibration is brought about when there is an external disturbance or conflict between the existing ideas and the incoming ideas (Dale, 1975). Thus, the student sees the environment from the point of view of his/her existing knowledge and mental thought patterns. Usually any individual is constantly assimilating new information - information that agrees with his/her existing ideas. Nevertheless, when a disturbance or conflict between what the learner already knows and the new information occurs, the new information may be rejected or modified before being accepted. In other cases the old idea may be
replaced or reorganised. The process is accommodation (Dale, 1975. It is the case when discrepant events or “counter experiences” are used (Brn, 1991; Gunstone, 1994) with the hope that the student will learn something (undergo a conceptual change) or otherwise the conflict may remain unresolved. Accommodation in this case is brought about by equilibration (achieving a state of balance) by either replacing the old idea with the new, or modifying the new idea for acceptance.

Equilibration, which is a Piagetian term, means a compensation for an external disturbance (Dale, 1975). The compensation is by having “... a changed viewpoint due to alterations to existing knowledge and modification of existing mental structures to incorporate the new aspects...” (Dale, 1975, pp.117-118).

However, not all that is presented to learners is accepted. Some students are resistant to conceptual change because of their various psychological or sociocultural beliefs. Hodson and Hodson (1998a) have interpreted this resistance by viewing such events from a Vygotskian perspective. This is an outlook that sees the group or social class as having a major role in shaping what its members learn or accept as useful information.

Among the factors influencing learning or acceptance of a new concept is social pressure. This may come, say, from other peers who hold a particular view. The peers could be those who occupy a special place in the student’s personal life with respect to what Hodson (1998) calls the “student power” hierarchy. They create immense social pressure to conform, leading to a development and legitimisation of a change of view. Sometimes the learner may hold membership of several social groups, each of which has rules to follow and exerts social pressures to conform. In Hodson’s view, “The personal framework
of understanding view of learning allows for the proliferation of meaning in response to entry into additional social groups” (p.53)

Social and cultural group identities, such as gender, ethnicity, religion and politics also impact heavily on learning (Hodson, 1998). Each of these cultures or subcultures (Aikenhead, 1996) provides the learner with different “lenses” through which experiences are interpreted and understood. These different ways of “seeing things” can develop into what Claxton (1993) calls “stances”. Stances tend to direct or guide individual students and their group activities or actions. In other words, stances constitute the ethics, the code of practice or rules that individual members of a group and the group as a whole subscribe to. These stances become the frameworks that guide students’ learning behaviour. Sticking to these stances is like ensuring allegiance to the norms and practices that constitute them. It is because of this that students always work to hold together all the social groups they associate with. They do this by implicitly or sometimes explicitly swearing allegiance to the social groups. Some of the learners have been found to “act out” by supplying responses that depend on the prevailing circumstances (Hodson, 1998; Matthews, 1994). In addition, as already argued and also will be argued later, analogies, which are embraced favourably by proponents of constructivism, may be major sources of misconceptions.

The constructivist approach has recently come under serious scrutiny. It is charged by some people with being simplistic, especially in its account of how misconceptions can be eliminated (Bloom, 1995; Cobern, 1996; Hodson &
Hodson, 1998a, 1998b; Matthews, 1998). These authors seem to concur on the point that the process of meaning making or construction is context bound and includes emotions, values, aesthetics, interpretive frameworks and personal experiences. It is precisely this perspective that Lagoke et al. (1997) have attempted to address by exploring the potential of environmental analogues in enhancing science concept learning among gender groups in Nigerian schools. In other words, they recognise the importance of social factors in analogical learning. This way, analogical learning is of a social constructivist nature. If learners already hold misconceptions in the analogue domain then it follows that the same or hybrid misconceptions will be transferred to the target domain. In other words, analogies do not necessarily eliminate misconceptions.

Clearly, a construct resulting from analogies should be in line with students’ correct preconceptions. Kelly (1955) defines a construct as simply a way in which some things are construed as being alike and yet different from others. Essentially, this is how an analogy works; presenting things or concepts that are different as though they are the same. The analogue and target concepts in an analogy are different and yet matching of attributes in these two domains or paradigms works as though the matched attributes are alike.

**Analogical Learning**

According to Zeitoun (1984), analogical learning, which embraces constructivist views of learning, takes place when the learners exhibit the following characteristics:
(i) Familiarity with the analogue,
(ii) No prior knowledge of the target,
(iii) Analogical reasoning ability,
(iv) Appropriate Piagetian cognitive levels (especially formal reasoning),
(v) Visual imagery,
(vi) Cognitive complexity.

It is important that the learners be familiar and comfortable with the analogue. Unfamiliar analogues may distract students’ attention from studying the target, and may also add a new load to the learning situation (Zeitoun, 1984). This is because the learner will be forced to understand both the analogue and the target at the same time. The use of unfamiliar analogues may even drive some learners into looking for alternative, more familiar analogues, which can be a recipe for chaos or confusion in conceptual learning, which according to Willner, 1964) is one “...reason for the usefulness of the principle of analogy in constructing new scientific hypotheses is that a relationship derived from a well understood realm may be extrapolated to a dimly understood one, and provide a key for understanding”. (p. 479)

Of course, the familiar will only facilitate learning to the extent that it is analogous to the topic (target). When familiar analogues are not available and easy-to-understand, unfamiliar material can be introduced to explain the target - somewhat in the style of an advance organiser (Ausubel, 1963, 1968). Advance organisers are “...typically written at the same level of abstraction, generality and
inclusiveness as the learning material [targets], and achieve their effect largely through repetition, condensation [(compressing material or summarising)], selective emphasis on central concepts and pre-familiarisation of the learner with certain key words” (Ausubel, 1963, p. 214). Clearly, what matters is the link between the analogue and target attributes and other conceptions that the student has. Having no prior knowledge of the target captures students’ interest and desire to learn the new material. In other words, “. . . analogies would produce best results when the learning material . . . is unfamiliar, i.e., the student has not yet developed a schema for this material” (Zeitoun, 1991, p.111).

Providing students with an analogy when they already possess relevant background knowledge about the target may interfere with their attention to learning target material. Furthermore, it may unnecessarily complicate the learning process and lead to confusion and resentment.

Analogical reasoning ability has to do with a learner’s ability to extract relationships in one domain, construct a closely equivalent relationship in a different domain and make careful inspection of both relationships to ensure that they match (Duit, 1991; Zeitoun, 1984). In other words, the learner should have the ability to understand and comprehend analogous arguments or comparisons and not to take them literally. For example, “aeroplane is to air as ship is to water” kind of reasoning. This way the learners become responsible for their own learning and the learning tools that facilitate this learning (Gunstone, 1994). It has, in this context, to do with the fact that learners are aware of analogies as
learning devices. Not only do the learners need analogical reasoning skills, they are assisted by being conscious of having them. The awareness and consciousness (metacognition\textsuperscript{4}) of having analogical reasoning skills and abilities give analogy use a prominent place among the tools of teaching science.

Learners at the Piagetian concrete operations stage (Dale, 1975) would require a bridging device to transit into the abstract. Analogies are just the right kind of devices to provide that bridge. In other words, analogies have a concretising function. They render the unobservable (abstract) attributes perceptible by comparing them with the concrete imaginable analogues (Zeitoun, 1984). It is therefore expected that learners at the concrete operational stage can benefit from the use of analogies in studying abstract concepts or material.

Analogical learning is also enhanced by a student’s ability to visualise the match between similar attributes of the analogue and target. Creating the image of the match or mismatch between the analogue and target attributes is a prerequisite to understanding the new (target) material. This is a high level cognition referred to as cognitive complexity – one of the structural characteristics that define individual differences. It is based on the belief that learners (people as distinct from other species, such as animals, birds, etc.) possess cognitive structures that

\textsuperscript{4}. Metacognition involves students’ ability to examine what they are thinking about, to make distinctions and comparisons, to see errors in what they are thinking about and how they are thinking about it, and to make self corrections (Ornstein & Lasley, 2000). \textbf{Note: Meta} signifies “aboutness” and is used to form new terms which signify a discourse, the theory or field of inquiry one level above its object which is also a discourse or field (Mautner, 1997).
are responsible for data processing. This structure has two components: 

*discriminating* structure - referring to partitioning of stimulation; and *integrating* structure - referring to how partitioned parts are related, combined, added, etc (Zeitoun, 1984). Zeitoun states that those people classified as cognitively complex are high on the discriminative structure and/or the integrative structure. They are said to be cognitively simple if they are low on these two structural indices. The significance of cognitive analogical learning is expressed by Zeitoun, 1984) as follows:

The integrative structure might be utilized when the students relate the analogous attributes of the analogue to that of the topic [(target)], the discriminative structure functions when the students isolate the irrelevant attributes between the analogue and the topic [(target)]. (p.113)

However, analogical learning, according to Zeitoun, is related to non-structural variables as well. These variables include:

(i) the complexity of the analogy, which refers to the number of conjoint (analogous) attributes that can be interpreted from an analogy statement,

(ii) the degree of concreteness of the analogy,

(iii) the number of analogues included in the analogy,

(iv) the format of presenting the analogy, which comprises two categories: mixed and separate. *Mixed* format involves a situation where both the analogue and the target are presented together and compared in the lesson – matched and unmatched attributes are pointed out carefully and systematically, for example, the blind spot and the optic nerve are compared with the photovoltaic cell. *Separate* format involves a situation
where the target and the analogue are presented independently, with the comparison being made later, for example, the camera and the human eye can be presented separately with similarities and differences being discussed much later.

The teaching strategies developed above comprise three major categories: (a) student self-developed analogy strategy, (b) guided teaching strategy and (c) expository teaching strategy in which the analogy is presented by the teacher (Zeitoun, 1984).

Whatever the approach, the aim is to have the students learn, say, correct physics concepts through the careful and correct match of similar attributes in both the analogue and the target. Unfortunately, things do not always work that way. Relationships can be misinterpreted or misunderstood, leading to the development of misconceptions. In this connection, Zeitoun (1984) says that “... some misconceptions might result from taking the relationship literally between the topic [(target)] and the analog[ue]. The misconceptions could be in the learning of the topic [(target)] as well as the analogue” (p.118).

Several models of teaching using analogies have been suggested, among the most significant of which are the General Model of Analogy Teaching (GMAT) (Zeitoun, 1984) and the Teaching With Analogies (TWA) model (Glynn, 1991).

The General Model of Analogy Teaching (GMAT) comprises nine stages:

1. Measure some of the students’ characteristics related to analogical learning in general.
2. Assess the prior knowledge of the students about the topic.

3. Analyse the learning material of the topic.

4. Judge the appropriateness of the analogy to be used.

5. Determine the characteristics of the analogy to be used.

6. Select the strategy of teaching and the medium of presenting the analogy.

7. Present the analogy to the students.

8. Evaluate the outcomes of using the analogy in teaching.

9. Revise the stages of the model.

Whereas on the surface this model looks appealing, it has certain weaknesses. For example, the first stage does not specify which characteristics or how they can be measured. Characteristics such as analogical reasoning ability, Piagetian cognitive levels, visual imagery and cognitive complexity (see discussion above) are not easy to measure moments before preparing a lesson. For analogical learning to be successful teachers need a simple model that they can use without too much hassle.

Glynn (1991) claims that his Teaching With Analogies (TWA) model can be used quickly in analysing any analogy for suitability or can be used to guide the construction of a suitable analogy. Of course, the value of an analogy is the ability to achieve its intended purpose. An analogy is good if it expresses new ideas in terms of what the students are already familiar with; it is bad if it is difficult to identify and map the important features that are similar (Glynn, 1991). It serves an explanatory purpose if among other things: (i) several features are
compared, (ii) most of the features compared are similar, and (iii) the features compared are of conceptual significance. Glynn’s TWA model is developed by utilising these qualities (among others) and comprises six stages:

1. Introduce the target.
2. Cue retrieval of analogue.
3. Identify relevant features of target and analogue.
5. Draw conclusions about target.
6. Indicate where the analogy breaks down.

This model is simple, clear and useful. However, like GMAT, it has weaknesses, though not of the same magnitude. They are relatively easy to fix. For example, the first stage is too general. It could be elaborated by incorporating some of the ideas from GMAT, such as assessing students’ prior knowledge of the target to determine whether the students already have the schemata or not. As stated earlier, analogies appear not to work well when the learners already have the schemata for the new concepts (targets). Duit (1991) reiterates the necessity of ensuring that students understand the analogy in the way the teacher thinks they should and that students see the similarities the teacher has in mind. Arguing for the case of learners having multiple meanings, Hodson (1998) says:

If meaning is, in part, socially constructed, it follows that different social groups can negotiate and construct different meanings. Moreover, since individuals have membership of more than one social group, they need to be familiar with more than one framework of understanding and to be able to access the knowledge, language and codes of behaviour appropriate to each group quickly and reliably, as the social situation changes. (pp. 74-75)
In this context of analogy use, it follows that it is important for teachers to establish common frameworks that are clear to all the students. Otherwise, if the teachers and the students operate in different frameworks, the teachers' intended meanings may not necessarily be the students' constructs.

Paulo Freire (1973), though not talking about analogies but about the role of agricultural extension workers and the peasant farmers, emphasised the need for the extension workers to enter into the farmers' cultural universe to communicate. He says, "... extension agents can communicate only by entering the cultural universe of peasants. This, they can do only by becoming vulnerable and ratifying the reciprocity which their role as educators dictates" (p. xii).

Learners' frameworks constitute their cultural universe. Moreover, as a parallel to Freire's extension agents, teachers have to enter students' cultural universe of thinking and meaning making. This can only happen when the teacher appreciates the students' position. Failure to do so, may lead to construction of misconceptions. Webber (1979) has voiced similar support for learner centredness in this matter by asserting that: "There is considerable evidence that the constructs, which are elicited from the subjects individually, are more personally meaningful to these subjects than are constructs applied to them from other sources" (p. 23). The reason for this is clear. Learners make sense of new information or experiences using their already existing knowledge (Brown & Clement, 1989). When this is not the case, there is the possibility that the analogue becomes confused with the theory it is serving, and when improperly used, it may serve as an obstruction to the learning process. It makes sense to
point out where the analogy does not work before making conclusions about the target. Thus, stage 6 in TWA becomes 5 and vice versa (Harrison & Treagust, 1994). By combining elements of GMAT and TWA, the researcher has proposed a simpler model, *Working With Analogies* (WWA) model (Nashon, 2000). It comprises six steps:

1. Assess students' knowledge of analogue
2. Assess students' prior knowledge of target
3. Identify analogue and target attributes.
4. Map similar attributes.
5. Point out unmapped attributes.
6. Draw conclusions about target.

This model closely matches what Zeitoun (1984) has described as the *way of presenting an analogy*:

1. The objective of the presentation is stated first. This is done as a way of directing students' focus and attention to the topic (target).
2. The analogue is introduced quickly if it is familiar to the students. It is here that the suggested model WWA is explicit - assessment of students' knowledge of the analogue. Previous research has shown that analogues can often be misconceived and can lead to the propagation of misconception into the learning of new material or target. The unfamiliar analogue might require some in-depth teaching until it becomes familiar to the learners.
3. A statement that initially connects the analogue to the topic (target) is presented, so that the students are cognitively prepared.

4. Analogous attributes are presented one at a time.

5. A transfer statement is presented.

6. Irrelevant attributes are presented.

   In WWA model, steps 5 and 6 are interchanged on the grounds that it makes sense to make a transfer statement after irrelevant or unmatched attributes have been identified and presented.

Summary

This chapter has outlined the nature of analogies, how they are constituted and developed or constructed. It has clarified some of the teaching situations in which examples, models and metaphors may be confused with analogies and has identified situations in which models, metaphors and examples are also analogies.

Three teaching models, GMAT and TWA, have been discussed. Weaknesses that exist in GMAT and TWA have also been identified. WWA is a derivative model that accommodates ideas from both GMAT and TWA. The Working With Analogies (WWA) model should be appealing to teachers as well as students because of its fit with the currently fashionable constructivist approaches to teaching and learning physics.

The next chapter discusses previous studies on analogy use a way of situating the research problem.
Chapter Three

Previous Studies and Problem Statement

This chapter reviews studies that have been done in classrooms by educational researchers on the use of analogies in teaching science-related subjects to high school students. The review identifies a deficiency in the literature on the use of analogies in teaching high school physics in the African context and, particularly, in the Kenyan context. Therefore, a statement of the problem that the current study addresses is provided and the questions directing the study are formulated.

Previous Studies

The research studies reviewed in this chapter were carried out in high school physics classes and directly or indirectly informed the planning of this study with respect to the research design, the methods of recording and style of reporting the findings. These studies include Black and Solomon (1987), Brna (1991), Clement (1993), Dagher (1995), Drost (1993), Duit (1991), Farmer (1985), Genter and Genter (1983), Hammer (1993), Harrison and Treagust (1993), Lagoke et al. (1997), Nemirovsky (1994), Pittman (1999), Roth (1991), Russell (1984), Schwartz (1993), Stavy and Tirosh (1993), Thiele and Treagust (1994), Treagust et al. (1992) and Wong (1993). Although not all of these studies focused on analogies, their findings and contexts provided valuable insight for this study. Some of the issues that these studies address include methodological issues,
categories of analogies, teachers’ use of analogies, students’ use of analogies and learning and use of analogies as a way of assessing understanding.

Methodological Issues

Nemirovsky (1994) discusses research findings in a journal article entitled, “On Ways of Symbolising”. This study provides a good example of a focused observation. After observing Laura, a student, Nemirovsky draws conclusions that are potentially very useful. However, some methodology questions may be raised: for example, can a single observation provide enough data for generalisation and universal applicability? Despite this uncertainty, Nemirovsky’s observation and data collection methods provide a wealth of ideas for other researchers. For example, his design of the study that focused on Laura’s understanding of “Ways of symbolizing”, interpretation of the data he collected and his way of keeping the student on task during observation without interfering with the students’ preferences are valuable to learn from.

Drost (1984), Hammer (1993), Roth (1991) and Russell (1984) have all conducted classroom observation case studies involving teachers and students. For example, Hammer (1993), in a research report entitled “Cognition and instruction”, examined and analysed an excerpt from a high school physics class discussion. The aim was to consider students’ work as inquiry to illustrate the teacher’s negotiation of the tension between inquiry-based learning and traditional content oriented teaching. Hammer’s study is similar to the present study in many
ways, including the careful observation of the teachers’ and the students’ behaviour.

**Categories of analogies**

Dagher and Cossman (1992) conducted a study that explored the nature of explanations used by science teachers in junior high school classrooms. Using classroom observation of twenty public school teachers in a total of 40 class periods, Dagher and Cossman generated 10 types of explanations that were conceptually related to one another. The ten categories or types of explanations generated are anthropomorphic, analogical, functional, genetic, mechanical, metaphysical, practical, rational, teleological and tautological.

*Anthropomorphism* is the making of a phenomenon familiar by attributing human characteristics to non-human agents involved; *analogical* explanations refers to the use of a familiar situation to explain a similar unfamiliar situation; *functional* explanation refers to a situation whereby a phenomenon is explained in terms of its immediate consequence (function); *genetic* explanation refers to a situation whereby an explanation is provided by relating antecedent sequence by events, e.g. a car may fail to stop after brakes are applied because the road became slippery after an oil spill from a leaking petrol tanker. Antecedent events in this case include, leakage from tanker, slippery road, application of brakes, and the event being explained is failure of the vehicle to stop; *mechanical* explanation refers to a situation where causal relationships that are generally physical in
nature; *metaphysical* involves making reference to supernatural agents as causes of phenomena; *practical* explanations involve instructions as to how to perform physical or mental operations; *rational* explanation involves presentation of evidence or warrant for a given claim in an effort (implicit/explicit) to compel belief; *teleological* explanation involves explaining a phenomenon in terms of how its immediate consequence (function) contributes to the probable attainment of an ultimate consequence (goal) in conjunction with other phenomena that are part of the same biological/physical system; and *tautological* explanation involves the reformulation of the how/why question or statement without adding any new information to its content (Dagher & Cossman, 1992, pp. 365 – 366).

From an analysis of 40 transcripts recorded in classrooms of 20 seventh and eighth grade science teachers, Dagher (1995) identified five general categories of analogies: *compound, narrative, procedural, peripheral* and *simple*.

*Compound* analogies are those involving instances where the teacher used more than one source (analogue) domain to explain several ideas related to the target (target comprises several attributes explained by drawing on their similarities to several analogues). For example, to explain a complete electric circuit, an understanding of attributes like current, resistance, potential difference, and cell or battery is essential. These are attributes of a single target - electric circuit. The attributes could be explained using multiple analogues. For example,

- current can be explained using its similarity to water flow;
- resistance can be compared to a stone placed in the path of water flow;
potential difference can be compared to pressure difference or difference in altitude or gradient of a landscape;

- cell or battery can be compared to a water pump.

*Narrative* analogies are those in which the teacher uses one source domain to explain several concepts in the target domain, for example, explaining the human body using the car as the analogue. The engine from the analogue (car) can be used to explain the various attributes of the human body (target). For instance, the functions of a car engine are similar to the function of the heart. When the car engine stops, the whole car stops as well. Similarly, when the heart stops functioning the human body stops functioning too. The car engine pumps gas into its pistons using a compression shaft linked to a fuel pump. And so on

*Procedural* analogies are those that pertain to procedures associated with the way in which science is carried out. These analogies do not necessarily focus on topical concepts but rather they pertain to (say) practice, conduct and processes. For example, if a teacher were to reinforce certain laboratory procedures, he/she may invoke a certain practice in life, such as, "Do not add water to an acid but add the acid to water", especially sulphuric acid. Analogically, this is like wanting to crush a tennis ball by throwing it on to a piece of rock in front of you. To understand the comparison, the following questions may be considered:

(a) What will happen to the tennis ball when it hits the piece of rock?

(b) What if the piece of rock is thrown onto the tennis ball?
Similarly,

(i) What happens when water is added to concentrated strong acid?

(ii) What happens when the concentrated acid is added to water?

The procedures in both cases have implications for the safety of the person doing the activity. In the case of a tennis ball being thrown onto a piece of rock, the ball bounces back and may hit the "thrower". And in the case of water being added to the concentrated sulphuric acid, the acid gets "spat" – that is, because of the immense heat of reaction generated, the water steams and causes "spitting" that could burn the person mixing water and acid. Because of the severe injury that is likely to result, the procedures in both cases have to be adhered to. Using one of the cases to explain or illustrate the other constitutes a procedural analogy.

*Peripheral analogies are secondary or accidental analogies that depend, say, on a single and central analogy. For example, Dagher (1995) uses the case of a telephone cable having several coloured transmission wires. Each wire is connected to a telephone in the home of a subscriber or telephone booth. This ensures that messages are sent to the right receivers. Similarly, the spinal cord has several nerves that link various parts of the body to the brain. Any message (action) from any part of the body must follow the correct channel (nerve) to the correct part of the brain for interpretation. Sometimes when a part of the cable system is cut, it is difficult to reconnect and therefore no messages can be exchanged between the message sender and the telephone subscriber. Similarly, when one of the nerves in the spinal cord is cut, or damaged, the message*
exchange between the part of the body and the corresponding part of the brain is lost. With the telephone lines, the line cut is easily repaired because of the colour coding. Without the colour coding, several things can happen, including a mistake in the connection of the cut wires, which can lead to messages from a particular sender going to the wrong receiver. In a similar way, this is what can happen to a person with a faulty spinal cord. Any damaged or cut nerve cannot be retouched easily, thus leading to no reception of messages by the brain from the damaged nerve, resulting in numbness. In other words, there will be no exchange of messages between the de-linked parts of the body and the brain. The main analogy is the telephone cable – spinal cord. But, a secondary analogy is introduced to explain the consequences of not colouring the telephone wire in a cable as compared to indistinctiveness of the nerves in the spinal cord. This analogy is still part of the main telephone cable-spinal cord analogy.

Simple analogies are those that require further development. Dagher (1995) gives the example of a food chain whereby a blueberry is considered to contain energy from the sun and grows until humans eat it. The plant (blueberry) stores energy from the sun just like a battery does. This analogy is considered simple not because it is easy to understand but because it requires further development. Storing energy is what characterises the analogy; further development includes the storage process, how energy from the sun (light) is changed to starch compared to how energy from the sun is stored in the form of chemical energy.
It should be noted that, for the purpose of the explanation, irrelevant attributes (Zeitoun, 1984) or unmatched attributes (Glynn, 1991; Harrison & Treagust, 1993) have been left out. However, for an analogy to be complete, the matched and unmatched attributes should be pointed out (discussed in chapter 2). Leaving out either type of attributes renders the analogy incomplete.

Treagust et al. (1992) observed analogies that were either enriched or simple. By enriched analogies, Treagust et al. meant those in which teachers not only carefully and clearly showed the relationship between the analogue and the target, but also dealt with the analogy’s shortcomings, pointing out when misunderstandings were likely to occur. Simple analogies, as in Dagher (1995), were those that required further development. Treagust et al. (1992) have implied the importance of teachers’ formal education in analogy use. More about this study is discussed in the section below.

**Teachers’ use of analogies**

Treagust et al. (1992) conducted a study that examined how science teachers used analogies in their regular teaching routines to enable students to comprehend scientific concepts. One of the key findings was the need to have analogies founded on a well-prepared teaching repertoire of analogies using specific content in specific contexts. In addition, they concluded that teachers should view learners as constructing their own knowledge rather than being mere passive recipients of teacher-presented knowledge.
Harrison and Treagust (1993) observed a grade-10 physics teacher teaching refraction in optics using a predetermined analogy. The analogy likened a ray of light as it passed from air into glass to a pair of wheels that changed direction as they rolled obliquely from a hard onto a soft surface. The study indicated that a competent teacher could integrate this systematic approach into a teaching repertoire that can result in better conceptual understanding of phenomena among students. The study also indicated that shared attributes should be precisely identified by the teacher or students, and that the un-shared attributes should be explicitly identified as well. Lastly, there was evidence of student understanding, likely to have been enhanced by systematic use of analogies (Harrison & Treagust, 1993).

Thiele and Treagust's (1994) study of four Australian chemistry teachers indicated that pictorial analogies (analogies that compare analogue and target attributes using pictures) were frequently used to enhance analogue familiarity and explanation, although the authors noted an absence of statements on the limitations of analogies. They also found that teachers used analogies only when in their (teachers') judgement, the students had not understood the initial explanations. In addition, there was a high frequency of analogue explanation, which the authors attributed to the lack of familiarity among the students. Thus, there were no planned analogies. Rather, teachers tended to draw analogues from their own experience or professional reading and did so in response to particular (unplanned) situations. Thiele and Treagust's (1994) study of four Australian
chemistry teachers indicated that pictorial analogies (analogies that compare analogue and target attributes using pictures) were frequently used to enhance analogue familiarity and explanation, although the authors noted an absence of statements on the limitations of analogies. They also found that teachers used analogies only when in their (teachers’) judgement, the students had not understood the initial explanations. In addition, there was a high frequency of analogue explanation, which the authors attributed to the lack of familiarity among the students. Thus, there were no planned analogies. Rather, teachers tended to draw analogues from their own experience or professional reading and did so in response to particular (unplanned) situations.

A study by Lagoke et al. (1997), similar to the current study in many ways, aimed at determining whether the use of environmental analogies can eliminate the gender gap in science concept attainment. It was based on the assumption that the use of analogies from the individual students’ socio-cultural environment can successfully act as a psychological bridge for the learning of science concepts. Two hundred and five male and forty-three female students in senior secondary (grade 11) selected from two schools in a certain township in Kaduna state, Nigeria, took part in the study. Using an adaptation of Glynn’s TWA model, a pre-test and a delayed post-test comparison showed that both male and female students attained an equivalent cognitive outcome after a six week treatment period; an indication that both boys and girls benefited significantly from teaching with environmental analogues. Environmental analogues, as used in this study,
refer to analogical linkages derived from the socio-cultural environment of the learner. Lagoke et al. (1997) state that,

The use of environmental analogues ensured that the introduction of new and unfamiliar concepts began from prior knowledge of the students, which bears specific relation to daily life of the students' society. Cultural traditions and beliefs in a given society were found to have exerted some effect on science teaching … (p.376)

This study was significant for the present study because it provided a background context similar to the one in which the current study was conducted. Furthermore, except for minor differences, any study of this nature conducted in Africa is likely to reveal the anthropomorphic element of the African’s worldview. Moreover, Nigeria and Kenya have gone through the same colonial experience. This colonial effect exposed the two countries to similar teaching styles, with both using English as a second language and as a medium of instruction in schools.

Students’ Use of Analogies and Learning

Brau (1991) shows how confrontation can be creative and useful in teaching and learning. In this study, a student first makes predictions about a particular situation; then the actual situation is presented. The intention is to incite “cognitive conflict”: the student experiences difficulties in reconciling the conceptualisation of the situation before and after experiencing the actual situation. This is an example of what Gunstone (1994) calls “Predict – Explain – Observe – Explain” (PEOE) approach. It is also an example of the discrepant
events strategy (discussed in chapter 2), in which students are presented with events that cause a conflict with the understanding they already have. Misconceptions are revealed in the predictions. The students get challenged when “correct” experiences are encountered. Brna’s study indicates that the student abandons or modifies the old conceptualisation of the situation in favour of the new experiences or relations (Posner et al., 1982). Brna’s approach had some weaknesses. For example, putting a student in some conceptual difficulty does not necessarily make conceptual change easy or lead to abandonment of previously held ideas (Cobern, 1996; Matthews, 1998). However, the research paper provides insights into ways of identifying misconceptions that children have about certain ideas or phenomena.

Although not directly related to the use of analogies, Brna’s study reinforces the idea that if the analogue has misconceptions, then those misconceptions are likely to be transferred to the target in an analogy. Therefore, to resolve any apparent conceptual conflicts within the analogue, it means providing the students with opportunities to express their conceptual understanding, which can then be confronted by counter situations that present plausible, intelligible and useful solutions/explanations. This way, fewer misconceptions (or none) may be transferred to the target. It is a fact that every new information learned has the potential of being used as an analogue for a similar new target.
In their research to find out if pupils could use taught analogies for electric current, Black and Solomon (1987) used three groups of third year secondary (13 – 14 year olds) students at the same comprehensive school. These groups were constituted from the thirtieth percentile downwards, using the results of tests and end-of-year examinations during the students’ first two years at the school. The three groups were taught electrical resistance, constant current flow in different parts of a circuit, and the decrease of current with increase of resistance. This was later followed by practical work with cells, ammeters, and home-made resistors of coiled wire. All the examples were confined to simple circuits, leaving the branched circuits for prediction using analogies. The first and the second groups were taught using fluid and electron analogies, respectively; the third group received instruction without use of any analogy. Prior to the teaching, everyone in the groups was asked to write about “How you imagine an electric current”. This was followed by two hours of instruction for each group. After instruction, a written test paper, a second piece of free writing about how the pupils imagined electric current, and some selected interviews were administered. For each problem, the pupils were required to give a reason for each of their answers. In this way, the researchers were able to assess how far the pupils were using analogies in their solutions. Black and Solomon noted little difference between the groups on the familiar problems. However, the difference became significant with answers to questions that required pupils to predict what would happen in a branched circuit. Black and Solomon concluded from these findings that
analogies do help pupils to predict what may happen in new situations. Once again this study has informed the current study in many valuable ways, including elicitation and discernment of learners’ ideas through testing and interviewing.

Stavy and Tirosh’s (1993) study determined “when an analogy is perceived as such” by presenting 7th - 12th grade students with problems related to:

(i) successive division of physical and geometrical objects, and
(ii) comparison of problems related to physical and geometrical objects.

From students' responses, the researchers concluded that:

(a) When having to solve an unfamiliar problem, students often use knowledge of a familiar problem they perceive as similar to the problem at hand;
(b) The success of any given analogy depends on several factors including the way in which the teacher sets up the problem;
(c) Similarity in structure of the problems determines whether students view a given problem as analogical to another one;
(d) Salient external features of a problem, rather than the theoretical framework, largely influence students' responses to problems; and
(e) Problems that involve the same process have a coercive effect on students' responses. This encourages students to view problems that involve the same process as identical.

In their advice to teachers and other analogy users, Stavy and Tirosh (1993) convey the importance of presenting students with structurally similar problems. They further recommend that teachers discuss with the students the validity of the
analogies they make and the theoretical framework in which the analogies are embedded. Again, there is a clear indication that metacognition - i.e., students’ awareness of the nature of analogues and what it is that they convey, depending on the commonly established theoretical framework - makes it easier for them to solve related problems.

Clement (1993) carried out a study that established the necessity of bridging analogies in more complex situations. This was found to be the case when dealing with content areas that were considered prone to misconceptions or alternative frameworks among students. Clement (1993) designed some lessons that used analogies to demonstrate to the students how a system of a “book-on-table” was similar to a “hand-on-spring”. The purpose of this analogy was to help students appreciate the fact that the table exerts an upward force to counter the book’s downward force. In other words, this analogy treats the table and the spring as matching attributes. But the results of this study show the reluctance of students to accept this premise. Clement’s findings show that a bridging analogy is needed as a transition to the “book-on-table”-“hand-on-spring” analogy.

Before moving to the hand-on-spring analogue, a less rigid setting was first used - a flexible cardboard. This pointed to the fact that the cardboard was exerting a resistive force. Otherwise, if it did not, then the bending would not have occurred in the flexible cardboard. Thus, a table offers the same resistive force at a flat level as the flexible cardboard. The flexible cardboard system was used as a bridging analogy. Clement (1993) concluded that anchoring examples
that tap intuitions which agree with accepted theories, can be used as starting points because:

(a) Not all preconceptions are misconceptions;
(b) Forming analogies between more difficult examples and an anchoring situation is an important instructional technique;
(c) Bridging by use of structural chains of intermediate analogies combined with group discussions encourages active thinking and helps students to believe in the validity of analogies;
(d) Explanatory models should be constructed from anchoring examples to provide an imageable mechanism, which explains target behaviour.

Wong (1993) examined analogical reasoning in contexts where understanding is generated from loosely organised, incomplete prior knowledge rather than transferred from a well-structured domain of understanding. The results of this study support the view that analogies generated by the learner are more meaningful and enhance understanding of the target concepts better than externally generated analogies. The results also reinforce the idea that learner generated analogies stimulate new inferences and insights. Wong (1993) concluded that individuals can productively harness the generative capacity of their own analogies in order to advance their conceptual understanding of scientific phenomena. Generative analogies are therefore considered tools to be used and modified as new understanding evolves.
In this study (by Wong), because of the different backgrounds of participants (chemistry, physics, biology, geology), different analogies were generated for the same concept - scientifically accepted account of air pressure – “Pressure is caused by collisions between colliding air molecules, and pressure inside and outside the syringe combine to create a resisting net force.” (Wong, 1993, p.1269). After experiencing this phenomenon using a gas syringe, the students were then required to generate their own analogies. Without going into the details of how the researcher went about ensuring this, it is amazing to note the kinds of analogies that the students generated, for example:

1. The concept of “Air particles move, collide and create pressure” was explained by the following student-generated analogies:
   (a) Air particles are like billiard balls in a container;
   (b) Air particles are [like] people moving in a room;
   (c) Air particles are like rubber balls inside the syringe.

2. The concept of “Outside air pressure is an important factor” was also explained by the following student-generated analogies:
   (a) Air particles are like rubber balls inside the syringe;
   (b) Air is like people moving in a room;
   (c) Pressure feels like a tug of war.

These examples illustrate the evaluative nature of analogies. To generate analogies of this kind is a sign of deep understanding of the phenomenon or concept.
Schwartz (1993) conducted two studies in which he explored whether adolescents can construct abstract visualisations to structure complex information. Using seventh, ninth and tenth grade students, Schwartz (1993) provided some students (but not others) with cues on visualisation. After administering pre and post-tests, the findings revealed that providing students with instruction in visualisation equipped them with the ability to develop a strategy that they could use to understand structure in complex and novel information. For example, one of the experiments required students to lay out or visualise information given in sentence form in a way that could make it easier to answer questions. The information was about transmission of effects through a natural pathway. Schwartz says that an appropriate visualisation for transmission problems integrates sentential information using three structural features:

(i) it indicates the direction of transmission such that one can order a cause and effect;
(ii) it indicates one-to-many relationships such that one can infer that a single cause has multiple effects;
(iii) it indicates many-to-one relationships such that one can infer that a single effect has multiple causes.

An example of such visualisation in physics relates to the energy cycle or conservation of energy. In a hydropower station, the energy stored in water in a reservoir has potential energy (Pe). This is converted to kinetic energy (Ke) when reservoir water falls onto the turbine. The turbine then turns a coil in a magnetic
field to generate electric current (electrical energy-Ee). The electrical energy is transmitted through wires and may be stored in batteries as chemical energy (Ce), used in lighting (Le), heating (heat energy, He), operating an electric bell (sound energy, Se), etc. An example of a visualisation model for this information is shown below:

Some of the energy relationships work both ways (conversion of energy is reversible, i.e. from one form to the other and vice versa), for example,

Other forms of energy can be generated from many other forms (multiple cause – single effect), for example,
Note, Le is in the form of solar energy.

While other forms can be generated from a single cause (one cause – multiple effects), e.g.,

In a study titled, “Flowing waters or teeming crowds: mental models of electricity”, Gentner and Gentner (1983) premised that particular analogies work well for certain aspects of the target, but less well for others. For example, their study showed that the water flow analogy worked well for series electric circuits while teeming crowds analogy worked well for parallel electric circuits.

Usually the attributes, which constitute the structures of analogues and targets, share common relations. The bulk of analogical models used in science exhibit structure mappings between complex systems. These analogies show that relational systems hold within two different domains (analogue and target). For
example, if a relation, $R$, exists between base (analogue) attributes $b_i$ and $b_j$ in a structural mapping $M$, the same relationship should exist between the target attributes $t_i$ and $t_j$, i.e.,

$$M : [R(b_i, b_j)] \rightarrow [R(t_i, t_j)]$$

Systematicity rule or principle captures the intuitive view that explanatory analogies are about systems of interconnected relations. Gentner and Gentner (1983) illustrate this by using the analogy of gravitational force between point masses and the force between point charges, i.e.,

$$F_g = G \frac{M_1 M_2}{R^2}, \quad F_e = k \frac{Q_1 Q_2}{R^2},$$

[Where $G$ is a constant, $F_g$ is the gravitational force between two point masses $M_1$ and $M_2$, placed a distance $R$ apart, and $F_e$ is the electrostatic force between two point charges $Q_1$ and $Q_2$, placed a distant $R$ apart, with $k$ as the constant specific to the medium in which the charges are imbedded.]

Gentner and Gentner (1983) identified two important analogies suitable for simple electricity: electricity and water analogy, and electricity and the moving crowd analogy. Water analogy transfers a system of relationships from hydraulics to electricity while the moving crowd analogy provides characteristics of a moving crowd of people in order to understand electric circuits. Two experiments were used. Experiment 1 elicited subjects' models of electric circuits.
by asking them whether their models predicted the types of inferences they made.

In experiment 2, subjects were taught different models of electric circuits and then compared them with the subsequent patterns of inferences. The question the subjects answer was: "How does current in a simple circuit with one battery (V) and one resistor (R) compare with the current in a circuit with two resistors in series or with the batteries in parallel?"

The results of the study showed that the subjects who drew incorrect conclusions about some of the combinations using the water analogy, later drew correct conclusions using the moving-crowd model, confirming that no single analogy can adequately explain a complex concept or has all correct properties. In this case, the water flow analogy led to better performance on the series resistor arrangements while the moving crowd analogy led to better performance on the parallel resistor arrangements.
Analogies as Assessment Tools

Pittman (1999) provides another perspective on analogy use - that of using analogy creation as a tool of assessment. Having students generate their own analogies reveals their deeper understanding of target concepts. Pittman used student-generated analogies as an alternative assessment method to the traditional multiple choice. He administered pre and posttests to these students with the purpose of measuring retention of factual information and gender differences. Pittman's study involved 700 seventh and eighth grade junior high school students. The school's ethnic composition was 90% white, 6% Asian, 1% African American and 3% other groups. The students received instruction on "Protein synthesis" using traditional methods. The topic was chosen because junior high students find it difficult to visualise. It should be noted that in the American context, Asian would refer to Chinese, Japanese and Korean students, while in Kenyan or British context, it would refer specifically to Indians or Pakistanis. The students were later trained by the teacher on how to think of analogies as A: B:: C: D, by working through some examples of the type, "Happy is to sad as generous is to ____". The class discussed and analysed several other teacher-generated analogies using the GMAT model. This was a way of training the students on how to generate analogies. After the training, groups of three students each generated their own analogies on sub-topics of their choice under "Protein Synthesis".

The following were inferred from students' responses:
(i) Student-generated analogies forced students to seek similarity relations between the information of protein synthesis and their prior knowledge.

(ii) The differences in sub-topic selection and the type of analogy created were gender dependent.

(iii) Sixty percent of the boys who took part in the study preferred student-generated analogies while 60% of the girls preferred teacher-generated analogies.

On the whole, Pittman’s study showed that student-generated analogies provided a better picture of student understanding about protein synthesis than the traditional paper and pencil tasks, such as multiple choice tests. This study is useful in understanding what lies underneath student-generated and teacher applied analogies.

Problem Statement and its Educational Significance

Although there have been numerous studies of analogy use, there are few in the area of teaching and learning physics, and almost none in the African context. It is this deficiency that prompted the researcher to study the nature of analogies used in teaching physics concepts to three form two (grade 10) physics classes in Kenya. In conducting this research, the focus was on the nature of analogies used in teaching physics concepts, how these analogies affected students’ preconceptions, and the new conceptions that the students formed.
Teaching of science requires the use of precise and clear language. This is sometimes not easy for second language speakers. Kenyan teachers use English, which is a second language, as a medium of instruction. As a result they encounter the same difficulties that other second language speakers elsewhere encounter. Therefore, they use analogies as a way out of these difficulties. This in itself warrants the need for a study like the current one.

Although poor performance in physics at high school level is a world-wide phenomenon, performance in Kenya in physics examinations, over many years, has been particularly disappointing. Any attempt to provide a solution is a benefit. Not many physicists are produced in Kenya, hence the need for a study of this kind; one that particularly looks at tools of instruction. And the fact that Kenya is a young country makes it necessary to research into ways of improving teaching strategies so that it can produce competent physicists who not only understand physics concepts but can relate them to the local environment.

Another important reason for this kind of study is derived from the fact that science is a culturally/socially determined and developed subject (Hodson, 1998; Matthews, 1994). This puts pressure on Kenya to develop its own repertoire of teaching strategies and tools that would make science accessible to as many students as possible, since it is the more effective and imaginative use of teaching tools such as analogies that can contribute to attempts to make science more attractive to Kenyan students.
Therefore, the findings of this study could help to sensitise teachers to the kinds of analogies they are actually using, identify the concepts they aim to explain and the students they teach. In addition, this study reveals the need for further research, which may lead to a dramatic change in physics instruction in multicultural societies. It is hoped that the study has established a comparative basis for further work in physics instruction in the developed and the developing world.

**Study Questions**

The following questions were instrumental in directing and providing the focus of the study:

1. What analogies are used?
2. What are their characteristics?
3. What alternative frameworks do students hold after analogous instructions?
Chapter Four
Methodology

The discussion in this chapter is about the methods and techniques used in collecting data on analogies used by form two physics teachers in one of the Kenyan high schools. It is a case study (see chapter one) method which involved field notes from direct classroom observation, videotapes of the observed lessons, class texts, the physics syllabus, formal and informal interviews with teachers and students, researchers’ and other teachers’ reflections and teachers’ notes and lesson plans as sources of data. Throughout the discussion in this chapter reference is made to data interpretation methods. This is because of the interdependence between the interpretation and the methods employed in the study. Without careful consideration of data interpretation, it is unlikely that useful data will be collected. In other words, useful data is something identified by the interpretation accorded to it.

It should be pointed out that the “dialogues” presented have excluded other connecting events or situations that the researcher considers unnecessary as far as analogies are concerned. In other words, although the data was collected naturalistically, the thesis is a reconstructed sequence to serve a particular argumentative purpose. Thus, the order in which the questions follow and link to each other does not always reflect the teachers’ actual presentations. Rather, questions have been deliberately selected because of their specific relevance to analogies. The study was conducted in the Kenyan context, which provided a background to the specific context of the study – the three classrooms in one of Kenya’s national schools. This has already been discussed in chapter one.
Below is a description of events in the specific case study. This will then be followed by a detailed description of the methods used in recording the data.

**The Case Study**

The study was conducted in three form two physics classes in a national school on the outskirts of the city of Nairobi, Kenya. The researcher observed all the physics lessons because it was not easy to determine in advance when the teachers would use analogies. The study aimed at capturing the analogies as the teachers presented them, whether planned or spontaneously generated; universal or local; and whether from the teachers or students.

Capturing the analogies in *situ* was one way of ensuring their authenticity. These analogies depended on the prevailing circumstances and most of those detected were in electricity. Necessarily, the topic of electricity comprises many abstract concepts. Abstract concepts are not easily understood by students, a concern that seems to have attracted the attention of many researchers (see Gentner & Gentner, 1983).

Three different physics classes were selected to provide variety within the same school. The school was chosen because of the availability of enough physics classes and teachers. In addition, the good performance consistently exhibited in physics examinations at the national level over the years influenced the researcher’s choice of the school for this research. Other reasons for choosing a national school included:

- Ethnic mix of student population,
- Minimum researcher bias in terms of capturing the analogies. This is because the school is multi-ethnic. Conducting research in his own ethnic community would have
biased the appreciation and recognition of the diversity of analogies that the teachers used. A national school has its own culture that accommodates views from all the cultures from which the students come.

- Researcher transportation and accommodation,
- The school is a boarding school, and therefore, extended classes are often held over the weekend.

Apart from recording data by the paper and pencil method, all the lessons were videotaped for reviewing.

Initially the researcher planned to have at least three formal interviews with each of the teachers and a sampled group of students regarding the analogies they used but this was abandoned because the prevailing circumstances favoured a more informal and interactive form of interview. This way, the teachers and the students provided genuine responses. They seemed to interpret formal interview as a way of being evaluated, despite assurances that this was not the case.

This study, therefore, represents a significant step in the direction of increasing our understanding of the nature of analogies used by teachers in teaching physics concepts in Kenyan high schools. Understanding this, it is hoped, will shed some light on the analogies teachers in other multicultural classrooms need to use to enhance the understanding and enjoyment of physics. The section below describes the methods used in collecting information on analogies, the three physics teachers and students in the three classrooms used.

**Methods of Collecting Data**

In brief, because the study involved classroom settings, the researcher mainly
used classroom observation methods and examined relevant materials such as class textbooks, the syllabus\(^5\) and teachers' notes. To complement this, the teachers and a randomly selected group of students were informally interviewed (Anderson, 1990; Zeitoun, 1984). Each class had three physics periods of 40 minutes each per week. One hundred and twenty six periods of 40 minutes each were observed. Prior to the beginning of every lesson, the researcher had meetings with the teachers, who briefed him on what they intended to teach next. Most high schools in Kenya have unofficially reorganised the 4-year high school syllabus into 3 years, the fourth year is unofficially dedicated to revision and preparation for national examinations.

In cases where teachers never intentionally used analogies to explain concepts, the researcher "teased out" the analogies during informal interviews. In many cases, the teachers later used the "teased out" analogies in review or remedial lessons. This was because the researcher established from the outset an environment of trust between himself and the class teachers, as well as with the students (Hopkins, 1993). Apart from gathering data from sources such as textbooks, syllabus, video and audio recorded lessons, student records (e.g. marks for tests and exams) kept by teachers, student workbooks, discussion with non participating teachers, reflections and the researchers own local understanding of the history of the school, direct classroom observation and interviewing of teachers, students and the lab technician were the major sources of data on the analogies the three physics teachers used.

\(^5\) The term syllabus is used here to mean a "list" of content items, objectives (expectations) and evaluation procedures. In Canada and USA, sometimes curriculum is used to refer to syllabus. However, curriculum is considered to mean more than just content and statement of expectations. It includes teaching strategies and all that the school engages in to enhance learning.
Classroom Observation

There are four methods of undertaking classroom observation: open, focused, structured and systematic observation (Hopkins, 1993). In this study, focused observation was used. The focus was on particular or specific aspect(s) of classroom events - analogy use (set out in chapter one).

During the lessons, the observer recorded in his notebook only events of research interest. An important element in establishing the climate of trust between the researcher and participants was agreeing on the focus of the research and what the teachers regarded as worthwhile. The context of the lessons was also discussed. For example, where lessons were conducted (laboratory or classroom), where the researcher sat during instruction and the length of time he stayed in each lesson (Hopkins, 1993). Most of these were further “fine-tuned” during the researcher’s meetings with the timetable master, the teachers and the Deputy Principal. The teachers readily agreed to the presence of a video camera in the classroom and, as indicated earlier, even offered to assist the researcher in recording the lessons. The researcher sought clarification on some of the classroom observations after the class, during recess or at any other time that was convenient. The teachers had no problem with this arrangement. To inform the researcher’s interpretive process, events were recorded as they happened and interpretation was conducted after discussing with the teachers concerned (Hopkins, 1993). Each episode was tape recorded and relevant portions transcribed verbatim to yield data for interpretive analysis, which was in line with the aim of the study – to observe and record analogies that physics teachers used and as a response to the first question formulated in chapter one and three (see page 82).

As indicated in chapter three, studies by Harrison and Treagust (1993), Thiele and
Treagust (1994), Treagust et al. (1992), Dagher and Cross (1992) and Lagoke et al. (1997) provided the researcher with methodological and interpretive skills and insights into the use of analogies. However, unlike Harrison and Treagust’s (1993) study, where the teacher was provided with a particular analogy to use, this study did not provide the teachers with specific analogies. Rather, it looked for analogies in situ - analogies which were analysed for suitability using Nashon’s (2000) derivative model, WWA (as outlined in chapter 2).

Wherever possible attributes (features) for the analogue and the corresponding target were identified for every analogy (see table of results in chapter five). In the original planning of this study, analogue and target features were to be recorded separately. But during the actual instruction, it was not possible to discern the individual attributes of the analogues and targets. The teachers did not always give similar attributes. Certainly, dissimilar attributes were not made explicit to the students, although WWA model requires that similar and dissimilar features be made explicit. Where dissimilar attributes were not clear, then informal follow-up interviews with the teachers and the students were conducted. The purpose of such informal follow-up interviews with the students was to elicit their understanding of the analogies and the new concepts taught via these analogies. In addition, interviewing the teachers ensured that the observed classroom events and the subsequent interpretation of these events were both accurate and faithfully represented. This also enabled the researcher to know in advance the contents of the next lesson.

In summary, during the focused classroom observation the following information was sought:

1. Analogues and attributes,
2. Targets and attributes,

3. Mapping of similar attributes (Shared attributes),

4. Unshared attributes,

5. Conclusions about the targets.

In addition, the analogies were checked for familiarity or unfamiliarity with the students. The researcher used paper and pencil to record field notes, which were complemented, as already stated, by video and audio recording.

During each lesson, the researcher recorded or described teacher and student behaviour, including student responses, explanations and interpretations. Video and audio recording of actual classroom sessions was essentially for the purpose of reference during analysis and for corroboration of information already recorded by paper and pencil methods. Occasionally, informal interviews and discursive encounters with both the teachers and the students were also video and audio recorded (Hopkins, 1993). In a sense, narrative description generated by the researcher involved artistic representation of events, their interpretation and associated meanings. In this study, the focus was on the meanings of classroom events and experiences in which the teachers and the students were involved (Eisner, 1981). Eisner puts it eloquently by saying, “What artistic approaches seek is to exploit the power of form to inform” (p.7). In other words, the purpose of classroom observation is to inform: to inform readers of events of focus and provide meanings for the observed events. For one to “inform”, the events have to be described as accurately as possible. The language one uses is accordingly formal. Thus, “... the syntactical rules to which such statements abide, allow little or no scope for poetic or metaphorical [writings]” (Eisner, 1981, p.6).
Narrative description differs from the formal use of language by placing a premium on idiosyncratic use of form. This involves visual and auditory form as well as discursive form. The purpose is to convey in non-literal as well as literal ways the meanings that the observer wishes to express. This eventually results in a “thick description” of the meanings and interpretations of the observed classroom events (Eisner, 1981). By recording the focal classroom events, one aims at “... helping people experience fragrance” (Eisner, 1981, p.10). Peshkin (1993) reinforces the idea of thick description by making reference to the inexhaustive subcategories of good research outcomes. In addition, Peshkin shows what good outcomes should do: explain or create generalisations, develop new concepts, elaborate on existing concepts, provide insights, clarify complexity and develop theory. All these, in the researcher’s view, resonate with Eisner’s (1981) idea of rich thick description.

The technique of paper and pencil recording was normatively used in the study; a skill which “... involves writing in narrative form what is relevant to the focus ... [for the] purpose of observation” (Stallings & Mohlman, 1988, p.472). Stallings and Mohlman further reiterate the purpose of normative description in classroom observation by saying:

The purpose is to record ... [analogy] the person ... uses during that period of time. It is not interpreted or summarised by the observer. Such records kept on a daily or weekly basis help develop a case study material. Over time patterns of behaviour are likely to emerge. (p. 472)

This method was chosen by the researcher because of inherent advantages, as listed by Stallings and Mohlman (1988):

(a) The context of the event can be described in a rich and holistic manner,

(b) The natural sequence of events is preserved,

(c) Unpredicted events can be reported.
The data in chapter five has elements of all these. The observation was based on a three phase cyclic model, an idea borrowed from Hopkins (1983). The three phases are:

- Planning the observational meeting,
- Actual classroom observations,
- Follow-up discussions.

The discussion centred on the reasons for using certain kinds of analogies, for example, spontaneous and localised analogies. Through this discussion, the researcher was able to elicit the meanings the teachers thought they conveyed to students via the analogies. This was also a way of ensuring that the contexts in which students understood (or attempted to understand) the analogies was accurate and clear (Bloom, 1995). The researcher also allowed for unseen instances such as informal talk after lessons that led to informal discussions. The students were asked to explain the analogies and make explicit their understanding of the analogues and targets during such informal discussions and interviews. Some students generated analogies that were similar to those their teachers had used. Generation of analogies by students can be an indication of their understanding of target concepts. Therefore, as discussed in chapter 3, analogies can be used as assessment tools (Pittman, 1999).

**Interviewing**

Interviews were used to complement the focused classroom observation method.
As Anderson (1990) notes, interviews "... can be conducted on all subjects by all types of interviewers and they can range from informal interviews [as] incidental sources of data to the primary source[s] of information used in research study" (p. 222). The interviewing in this study was informal, sometimes after classes or during interactive encounters (e.g., practical time, recess time). Such interviews were important in clarifying the teachers' understanding and intentions of the analogies they used. They also helped in eliciting students' understanding of the concepts and the associated analogies after instruction.

Anderson (1990) points out that,

There can be many contexts for interviews which may encompass a variety of settings ... The typical interview includes two people, and when face to face, most often takes place at the respondent's place of work, whether home, office or school. (p. 224)

All the informal interviews during the study were face to face and at the teachers' and students' work place, classrooms and laboratories. In addition, as Anderson (1990) further notes that "The interviewer is interested in building understanding and in this sense the interview is a ... clarification situation in which the respondent ... clarifies to the interviewer ... about events and personal perspectives or unclear intentions" (p. 224).

The researcher focused on identifying, understanding and recording the analogies the teachers used. When any of these was not clear, an informal interview with the teachers was pursued. The researcher planned to have at least eighteen formal interviews with both the teachers and sampled groups of students. However, as explained earlier, this was not possible. The style of interviewing was changed as the study progressed, because the researcher had to be flexible and responsive to the specific nature of the research situation.
Fontana and Frey (1994) reckon that no single interview style that fits several occasions or all respondents exists. Therefore, they advise interviewers to be aware of respondents' differences that may call for flexibility in making adjustments for unanticipated developments. It is also important that interviewers understand respondents' work and other forces that might stimulate or retard responses.

Because of this understanding, the researcher was morally bound to exercise flexibility in the course of the study. As mentioned in the preceding section, the interview was for the purpose of information gathering and clarification (Anderson, 1990).

**Techniques of Recording Data**

The technique of simple paper and pencil recording was used to record any portions of instructions that were perceived to contain analogies. This was important in enabling the researcher to frame follow-up questions to teachers and students during informal discussions after the lessons. To supplement this, the researcher video recorded all lessons. This enabled him to review the lessons in their entirety.

To ensure that all analogies deployed by teachers were identified and properly understood, the researcher had to be vigilant, in part because the language used did not always clearly indicate the analogy in use. Consequently, it was necessary to capture the verbal aspect accurately by audio taping the lessons. In this respect, the field notes taken while observing proved to be very informative and indispensable during the review of the videotaped lessons. Video recording was particularly useful, since it was not always possible to capture all the non-verbal communication, such as gestures. Reviewing the recordings made it possible for the researcher to identify and extract such details. In fact, non-verbal communication was an integral part of the cultural environment.
Trustworthiness/credibility of the data and conclusions

Trustworthiness and credibility are used in qualitative studies of naturalistic nature to describe what in quantitative terms is called validity. Validity would therefore be the accuracy and truthfulness (Johnson & David, 1998; Lincoln & Guba, 1985) in the findings. In this study, being a qualitative case study, the concern was how dependable and believable the findings were.

Interviewing the teacher and the students and consulting other related materials, such as physics texts, was a way of corroborating the observations, interpretations and any derived meanings, assertions, claims and conclusions that the researcher made. Triangulation is the commonly used term for this attempt to ensure trustworthiness (Mathison, 1988; Maxwell, 1996). Maxwell says, “This reduces the risk that [one’s] conclusions reflect only the systematic biases or limitations of a specific method and it allows [one] to gain better assessment of the validity and generality of the explanations that [he/she] develop[s]” (p.75).

The recording of observations was as factual as possible; all attempts to judge, make claims, draw conclusions or interpret the data were made after discussion with the relevant teachers and students. Furthermore, many recordings, especially video and audio recordings, were studied by the teachers to verify their performance during instruction. However, there was not sufficient time for the teachers and students to view and listen to all the recordings. But, they viewed what they could, to meet Walker’s (1990) condition that says research as goes “...beyond the effective portrayal of individual instances and to ... be on guard against using [this] case study to smuggle ... [one’s] own or single values into the system” (p.203). It is with this in mind that the researcher discussed his
observations with the teachers to establish their versions of events and episodes. The researcher occasionally discussed with both the teachers and the students before passing judgements, drawing conclusions and making claims or assertions.

**Ethical Issues**

Whereas the researcher was morally bound to cultivate good working relationships with those involved in the study as an on-going and informal commitment, ethical issues such as anonymity and confidentiality of participants, personal freedoms, ownership of the data, and limitations of researcher involvement in class matters, were *explicitly* addressed and agreed upon between the teachers and the researcher. Some of the key issues are recognised by Walker (1996), who points out some of the puzzling questions that necessitate formally agreed guidelines by the parties involved in the research:

- Should the observer be involved in the situation being studied?
- Is it possible to offer informants confidentiality?
- Is it right to do so?
- How should requests for access to data during the course of study be handled?
- What procedures should be accepted in obtaining release of data for final publication?

Some of the questions and issues, such as whether the researcher was to be involved in the situation that is being studied or not, were addressed before the study was conducted. For example, the analogies that were sought by the researcher were to come
from the teachers, the classes, the students, curriculum materials and so on, but not from
the researcher himself. However, through interviewing, there were occasions when the
researcher "teased out" some of the analogies from the teachers and students. Other
questions in Walker's list, like how requests for access to the data during the course of
the study were handled, were never an issue in this study. However, the office of the
President of the Republic of Kenya, had and still has the authority, as specified in the
research permit, to demand access to the data at anytime. But this is rare. The trust that
existed between the researcher and teachers, the school administration and the students
diminished any possibility of a demand for access to the data. In any case the
researcher's field notebook was always left in the laboratory and many times the teachers
and the lab technician could have had access to it, had they chosen. Indeed, there were
occasions when a teacher would place it in a drawer after the researcher had left it on top
of the desk in the lab prep room.

The rest of the questions, like offering informants confidentiality and whether it
was right to do so or not, and what procedures were accepted in obtaining release of data
for final publication, were addressed by the researcher when he obtained the following
agreements:

1. Complete ethical review form - statement of intent and completion of
   ethical review protocol form; a requirement of the University of Toronto;
2. Informed (strong verbal) consent from the teachers;
3. Informed consent from the school Principal and the written consent from
   the Office of the President of the Republic of Kenya, as required by
   Kenyan law.
The procedure in Kenya is that the researcher privately identifies the study location, and makes his/her own background arrangements by privately seeking consent from the teachers and the Principal concerned. Usually such consent is verbal. However, only the office of the President can provide clearance for research. The researcher obtained all the required permission: he had firm verbal agreement from the teachers and the school Principal before proceeding to the Office of the President of the Republic of Kenya for a research permit. At the OP, the researcher completed application forms and paid a required fee of one thousand Kenya shillings (about US$15). In addition, the researcher supplied three certified passport size photographs of himself and three copies of the research proposal. One week later, a permit to do research was granted and an identification card, which bore his photograph, was issued.

In the research authorisation letter (see appendix 2), the researcher was required to report to the District Commissioner of the District where the research station (school) was located. This procedure has several advantages to the researcher. First, the relevant District administration is aware of the researcher’s presence in the area. Second, if access to classified information is required, the researcher knows where to get it. Third, though not the least, the researcher’s own security is improved.

In the Canadian context, the researcher would have sought consent from the students – those above the age of 18 years old or from their parents. In Kenya, since all national schools are boarding, the school’s board of Governors (BOG), with the Principal as its secretary, is vested with responsibility of making decisions on behalf of the students’ parents in conjunction with the Parents Teachers Association (PTA). This is because, as stated in chapter one, the students in national schools come from all over the
country and dealing with individual parents is problematic. Therefore, the person managing day-to-day affairs of the school and members is the Principal.

As has already been said, one has to obtain firm verbal commitment from the Principal and the teachers before seeking permission from the OP. What this means is that one establishes a good rapport with the teachers long before permission from the OP is granted and starting the research. In addition, students and the rest of the non-participating staff are made aware of the researcher’s presence in the school, the reason for being there and for how long.

Without good rapport with the teachers, school administration and the rest of the teaching and non-teaching staff, it would be impossible for any researcher to do credible research in the school. It is therefore incumbent upon the researcher, as it was in this case, to maintain good professional working relationship with everyone associated with the school.

Students also have ways of expressing their displeasure, if they are unhappy with the way things are going. The extreme is that they can strike and fail to come to class. This would be the last thing any researcher, the teachers and the school administration would want. As a show of appreciation of the researcher’s presence and stay in the school, the Principal wrote him a letter of commendation. The letter cannot be published because doing so will violate the confidentiality spirit. However, such a letter can be used as reference in other areas where the contexts of the research data is not revealed or required. For example, if the researcher were to apply for another research permit in the future, such a letter will be crucial.
Because of confidentiality and rights of participants, the name of the school is not disclosed in this thesis, and the teachers and their class identities have been assigned alphabetical letters W, T and S. Any students mentioned in the discussion have been assigned letters or numbers.

The chapter that follows presents the data collected on analogies. It also presents data on alternative frameworks that students displayed in concepts of electromotive force, back electromotive force and potential difference. These were extracted from students’ responses to test questions that included those taught analogously. It was an established departmental policy to test students on topics covered after every topic or two to three weeks later, after completing three topics. This test was given after three topics, mechanics, machines and electricity were covered — almost the end of the researcher’s time in the school. All members of the department set such tests. The researcher was involved as well since he was a member of the department for the 14 weeks of the study. As has already been stated, the researcher was interested in concepts that were taught analogously, most of which were in electricity. Although the test covered mechanics, machines and electricity, the researcher was interested in students’ responses to the following question:

“Explain what the following terms mean: electromotive force, current, resistance, back electromotive force, variable resistor, constant resistor, fuse, potential difference, open circuit, closed circuit and conventional current.”

In addition to these data, the chapter that follows describes the context in which the analogies and students’ alternative frameworks were located. A discussion of inferences and assertions is also provided.
Chapter Five

Data and Analysis

This chapter addresses the questions set out in chapter three to direct the collection of data on the analogies Kenyan high school teachers in three form two physics classes used in teaching physics concepts.

The first question sought to identify the analogies, the second question sought to examine the characteristics of these analogies and the third sought to determine the alternative frameworks that students possessed after being taught physics concepts using the identified analogies. Therefore, the data that follows, together with the description of the context in which the analogies were located and the interpretative discussion, form a direct response to the three questions stated in chapters one and four.

Data

Two sets of data have been described below - data from classroom observation and interviews and data on students' post instruction alternative meanings of analogous concepts obtained from their written responses to test questions. The test was set after three topics, mechanics, machines and electricity were taught, as is the departmental policy in the school. The policy requires that students be tested after every two or three weeks (after covering one topic) and after covering three topics.
Most of the data on analogies were obtained from direct classroom observation, though some were obtained from interviews with the teachers and students. There were hardly any analogies detected in the form two main class textbook except water-electricity analogy found in “Ordinary Level Physics” (Abbott, 1984). In addition, as indicated above, data were also obtained from a final test that was given by the teachers as part of a departmental policy. Students’ responses to the test that covered mechanics, machines and electricity were analysed with a deliberate focus on analogously taught concepts. Alternative frameworks were therefore extracted.

Observation was conducted in three form two physics classes taught by three physics teachers: S, W and T. Each class had about 40 students. Because of the high school quarter system of student selection, these students represented most of the tribes in Kenya. The three classes were in the same school and the timetable was organised in a way that ensured no overlap in physics lessons. This enabled the researcher to observe all the physics lessons in the three classes.

Three main topics were taught during the 14-week observation: mechanics, machines and electricity. Most of the analogies detected were in the area of electricity. There were very few analogies used in mechanics and machines. Consequently, only analogies and students’ alternative frameworks from electricity are described and discussed in this chapter.

Below is a list of key analogies detected during the 14-week classroom observation. They are given in the form of analogue - target domains. Where it
has not been possible to separate the analogies into analogue - target domains, a description of the whole analogy is provided. S, W and T refer to the teachers and their respective classes. These are arbitrary letters and they neither refer to the actual classes nor the order in which the classes and lessons were taught. The second part of the data presentation concerns students’ conceptual frameworks. These data were extracted from a sampled set of 23 answer sheets to the test that covered mechanics, machines and electricity. As stated above, only responses to questions on analogous concepts in electricity are considered.

Results
Data on Analogies

<table>
<thead>
<tr>
<th>ANALOGUE</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>1S. Limiting students’ operations in school so that they do not stray.</td>
<td>Function of magnetic material in a current-carrying solenoid is intended to concentrate magnetism. “Magnetic material is used to prevent straying of magnetism.”</td>
</tr>
<tr>
<td>2S. Putting students’ behaviour on the right course when they keep alternating between bad and good behaviour, i.e “rectifying behaviour.”</td>
<td>Rectification of alternating current (ac) current using rectifiers.</td>
</tr>
<tr>
<td>3T.</td>
<td>A stone raised above the ground: the higher it is the greater the potential energy.</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4T.</td>
<td>Force causes motion.</td>
</tr>
<tr>
<td>5T.</td>
<td>Work and energy are both measured in joules.</td>
</tr>
<tr>
<td>6T.</td>
<td>Some men have a willingness to give while others do not give easily.</td>
</tr>
<tr>
<td>7T.</td>
<td>In a mixed boarding school, boys and girls are prevented from mixing outside their classes by building fences around their residences. And if contact is to be allowed, we look for ways of removing the fences.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8S. A Presidential bodyguard must protect the President, even if it requires the bodyguard to put his/her life on the line in defence of the President. A fuse is a wire of low melting point. It melts when there is excessive current, thus preventing damage to the electric appliance connected to it.

9W. In geography, we talk of water current, air current and so on. What is water and air current? Water current is the movement of water from one region to another. Electric current is the movement of electrons from negative to positive terminals. Electron current can be compared to water current.

10W. When a vehicle is moving along a road, observers inside the vehicle see electricity posts, telephone posts, trees, etc, on the side of the road moving in the opposite direction to the vehicle. * In any cell, electrons flow from -ve to +ve terminals while the conventional current flows from +ve to -ve terminals through an external circuit.

*Movement of vehicle and passengers compares with electron current (electron flow) and apparent movement of roadside objects is compared to conventional current.*

11W. A water tank having inlet and outlet pipes can be drained and refilled continuously. Water tanks are not refilled through outlet pipes, instead, they are refilled through inlet pipes (see figure 1) Rechargeable are called secondary cells (accumulators). They get continuously recharged in cars by alternators. The charging current enters through the +ve terminal. Terminals are reversed, i.e., +ves are connected together and -ves are similarly connected - charging current passes through opposite terminals, unlike refilling a water tank.

Teacher: What is an accumulator?
Students: [in a chorus] Many cells. *
*A number of students confused a battery with an accumulator by suggesting that accumulating (piling up) of cells constituted an accumulator.*

| 12S. Leaving a metallic water tank empty for a long time makes it rusty and it may no longer be used to store water. In fact, in some cases it ends up leaking. **Teacher:** What should we do to ensure that this does not happen? **Student:** Fill it with water all the time. **Teacher:** When left for a long time the rust spreads and the tank can no longer store water. | When the cell is discharged the electrodes get coated with a white substance called lead sulphate. **Teacher:** What should we do to ensure this does not happen? **Student:** It should be recharged by heating. **Teacher:** When left for a long time the white coating crystallizes and recharging cannot take place. |

| 13T A person who is generous at giving out all he/she can, gets to a point when he/she can no longer continue giving but instead this person becomes in need. | In alkaline cells nickel hydroxide is the +ve electrode and cadmium is used as the -ve electrode. The nickel electrode cannot give out electrons. Nickel ions have already given out electrons and can no longer give out more. **Teacher:** It says, I have already given out what I could and no more, but now I can take in electrons. |
14T. **Teacher:** When a river is flowing a current develops. Wind flows from a high pressure zone to a low pressure zone, i.e., from point G to H respectively.

**Teacher:** What is the difference in G and H?

**Student:** Pressure difference.

**Teacher:** Something similar to diffusion, isn't it?

Flowing from a region of higher concentration to a region of low concentration. Similar to a river flow from a high altitude to a low altitude.

High level and low level give a difference in altitude.

The difference in altitude causes the river to flow.

**Teacher:** What is electric current?

**Students:** A flow of electrons in a circuit.

**Teacher:** I disagree. If we talk of electric current it means we have other currents. What are they?

**Students:** Ocean current, conventional current.

**Teacher:** That is still electric current, isn't it?

**Student:** Air current.

**Teacher:** When a river is flowing a current develops. There is something common to all currents.

High potential and low potential give potential difference which causes the current to flow.

The electric current follows the same pattern as the river flow. The terminals are at different potentials.

15T. **Masculine (male)**

**Feminine (female)**

**Teacher:** The giver must ensure he gives.*

+ve terminal of a battery.

−ve terminal.

Conventional current from +ve terminal to the −ve terminal. Current flows due to a potential difference.

**Teacher:** If there is no difference in potential, . . . no current flows.

---

*This statement implies in material sense that the male is the one who always gives while the female is on the receiving end. Despite this implicit gender bias, the statement's meaning should be seen in the context of the whole analogy.*
16S. **Teacher:** Who can give us a daily experience that would function like a fuse?

**Student 1:** Like in school life, one sacrifices student time to achieve higher.

**Student 2:** In school life you can be given an option of kneeling down or get strokes. You sacrifice your pride by accepting strokes in order to continue with school.

**Student 3:** An employee, who is asked to do an inhuman job for less salary, opts for a sack than to put his dignity on the line (in jeopardy).

<table>
<thead>
<tr>
<th>17T.</th>
<th>18W. An interview with students and their teacher about resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Friction:</strong> When a car is moving, it experiences a back opposing force called friction. Friction has to be overcome in order for the car to continue moving.</td>
<td><strong>Researcher:</strong> Tell me how variable and constant [(fixed)] resistors work?</td>
</tr>
<tr>
<td><strong>Direct current (dc) motor:</strong> The back emf in a dc motor must be overcome. The driving emf should be greater than the back emf (bemf).</td>
<td><strong>Teacher:</strong> How a fuse functions: A fuse protects electric appliances. Its purpose is to safeguard another component. It melts, and that is the end of its life.</td>
</tr>
</tbody>
</table>

Isolating only analogue and target attributes for the next three, 18W, 19W and 20T would deny the reader the other implicit messages that were conveyed and the logic implied in the discussion may be obscured. Therefore, as stated earlier, a description or presentation of the whole episode in which the analogy is located is provided.
Student M: Peer pressure. Peers usually endeavour to oppose a
decision they do not like OR If you do not stay firm in your
decision. [Variable resistor].

Student N: In a river water flow, an obstacle like a stone would oppose
its flow. [Constant resistor]
OR In athletics, other runners always try to stop you from
running to win. [Variable resistor].

Student P: Like prefects always oppose wrongdoing, no matter what.
Their opposition is the same [means not ready to soften].
OR Like charges opposing each other.

Student Q: Accidents on the road would not allow the smooth
movement of traffic [constant resistors].

Student R: A pothole on the road would interfere with the smooth
running of vehicles OR Running of water on a pot-holed
road [constant resistor].

Note: The varied nature of student-supplied analogues confirms Pittman’s
(1999) notion of using analogies as a way of assessing students’ deeper
understanding of the target.

Teacher’s version:

Teacher: Athletes always experience resistance from wind that blows in the
opposite direction OR Consider water in the tank with an outlet pipe at
the bottom. The size of the pipe determines the amount of water let out.
19W. [Water flow analogy (recommended in the syllabus and found in standard books)].

Teacher: Why does water flow from one end of the pipe to the other?

Student: Pressure.

Teacher: Yes, pressure difference like between X and Y gives rise to a water current. Similarly, electric current flows due to a potential difference.

Interview with teacher

Researcher: Why did you use potential energy instead of pressure in your water flow analogy?

Teacher: My experience is that when I use pressure in water tanks, students are not convinced that the cell exerts pressure. But when I use energy, from their knowledge of chemical energy conversion to electrical energy, they get convinced.
**Researcher:** And why did you use two water tanks (reservoirs) as opposed to the circulatory flow diagram that most people use?[see figure 3a below]

**Teacher:** I have found that I can explain everything in an electric circuit using my diagram. The water circuit diagram is difficult because it does not explain emf well. Again, when we are solving problems, a pump is considered a resistor and yet, here, it is providing emf. The students get confused (See figure 3b above).

**Researcher:** Why didn’t you refer to friction and the experience of walking?

**Teacher:** That is not easy to explain. I found it easier to use a moving car. But it also conflicts with, we *walk because of friction.* [Although
not stated, there was a high possibility that students would not have been convinced due to the widely held belief that people do not just fall without some other evil power controlled and sent by an evil person].

20T. **Teacher:** What is a couple in a life situation?

**Student:** A man and a woman.

**Teacher:** Not just a man and a woman, but they must be married. Not a man and a man. Therefore, there must be something to do with opposites. This is similar to the couple of forces that produces a turning effect on the coil in a magnetic field. [This was in reference to a dc motor sketch (see figure 4) where the armature stalls due to back emf that has to be overcome].

---

**A dc motor Circuit**

*Figure 4*
Data on Analogous Concepts: Students’ Alternative Frameworks

All the teachers in the physics department, in collaboration with the researcher, designed a test as described earlier. The test covered the area of mechanics, machines and electricity. However, the researcher’s sole interest was in students’ responses to questions in electricity. This is because, as stated earlier, only the topic of electricity generated a significant number of analogies. The test items on electricity simply required the students to explain the terms that were taught using analogies. The terms included electromotive force, back emf and potential difference (see chapter four, page 99).

Only 23 of the 120 answer sheets were analysed. These 23 were randomly selected. In each class, every 1st, 7th, 13th, 17th, 25th, 31st and 37th sheet was selected. However, two classes had more than 40 students and, therefore, the sampling in one class included answer sheet number 43. The other class had 41 students and therefore the 41st answer sheet was selected as well. The class samples were combined and analysed. This represented about 20% of the participating students. The sampling was based on the records on previous tests in the school, which showed that about 20% of each class provided a mixed sample from which enough alternative frameworks could be obtained, thus giving enough data from which a case is made. Despite the possibility that the other 80% of the answer sheets contained alternative frameworks of a different kind, those examined (23 answer sheets) provided enough data for research purposes. The data helped the researcher to develop the argument about the nature of analogies
and the students who were taught using these analogies. Some of the excerpts in which alternative frameworks are located are also presented. The boxed portions contain misconceptions (alternative frameworks).

**Lesson Excerpt**

The lesson was about wet and dry cells. Wet Lanlanche´ cells are not common to students in Kenya, therefore, majority of the students in early high school classes would not have had prior experience with these cells. However, nearly every high school student would have some prior experiences with dry cells and the majority would already have formed or constructed theories about their experiences with dry cells. In rural Kenya, it is common to find people putting used dry Lanlanche´ cells in the sunshine for “renewal”. The practice is so common that anybody who has once done this is tempted to believe that the recharging process is by heating. This is probably because the cells tend to perform slightly better than before they were displayed in the hot sunshine, an idea that one of the teachers and some of his students conveyed during a discussion about secondary cells.

**Teacher: “What are some of the changes that occur after a dry cell is completely used up?”**

**Student F: “It becomes softer.”**

**Teacher: “Why?”**

**Student G: “The hydrogen gas produced makes it so.”**

**Teacher: “Are you sure?”**
Teacher: “What is the role of manganese dioxide? And why is it close to the carbon rod?”

Student H: “Manganese dioxide is a depolariser.”

Teacher: “That’s right. But you have not answered my two questions.”

Student H: Manganese dioxide is closer to the carbon rod to eliminate polarisation caused by hydrogen gas produced at the rod.”

Teacher: “Could there be water?”

Students: “No! no! no!”

Student I: “Sir, this is a dry cell. Also, there is starch as you told us.”

Student K: “Sir, why is it that used-up dry cells can be reused?”

Teacher: “Is it? I am not sure. Maybe you are talking about the next class of cells called secondary cells.”

Teacher: “Simple cells, dry and wet Laclanche’ cells are called primary cells. The reaction is irreversible. These cells are not rechargeable.”

Student L: “Before cells are used in a radio some people wrap them with polythene paper. Why?”

Teacher: “To prevent the solution from leaking onto the terminals”

Student V: “Does it mean that current will flow through polythene paper?”

Teacher: “Let us draw it” [The teacher draws a cell being wrapped in a polythene paper excluding the cell ends].

Teacher: “Polythene paper is wrapped in a way that does not block the cell ends or contacts. Polythene paper does not conduct electricity.”
**Teacher**: [Explains what secondary cells are, followed by the dialogue below:]

**Teacher**: "We have seen that primary cells are not rechargeable but secondary cells are."

**Teacher**: "Now, who can give us examples of secondary cells?"

**Student V**: "Dry cell."

**Student H**: "Not really. Lead-acid cell."

**Teacher**: "That's correct."

**Student V**: "Sir, I am right."

**Teacher**: "How?"

**Student V**: "When the cell is finished, I usually put it to recharge in the hot sunshine."

**Teacher**: "I have seen some people do that but it doesn't last."

**Student Z**: "But also car batteries. People keep on buying new ones."

**Teacher**: "When you have many cells connected together, then you have a battery."

**Teacher**: "Secondary cells are also called accumulators. They can be recharged."

**Teacher**: [Teacher invites the class to the front bench in the lab to examine disused and disfunctional accumulators. He explains to the students what happens to a lead acid cell while in use]

**Teacher**: "What should be done to remove the white lead sulphate?"

**Student V**: "Something that can provide heat to remove the white substance."
[This is the same student who had suggested earlier in the lesson that a dry cell is rechargeable by placing it in the hot sunshine].

**Teacher:** “No, not really. It is dangerous. Any hydrogen produced can explode and cause fire.” [Teacher then takes time to explain the process of charging a secondary cell].

**Teacher:** “Today we have discussed primary and secondary cells. You gave me enough examples of primary cells. Can you please give me more examples of secondary cells?”

**Student Z:** “accumulator.”

**Teacher:** “Correct. But what is an accumulator?”

**Students:** [In a chorus] “Many cells.”

**Teacher:** “Where are accumulators mostly used?”

**Students:** “in cars”

**Student H:** “No. Cars use batteries.”

**Teacher:** “What is the difference between accumulators and batteries?”

**Teacher:** “Read more on this section and bring your answers next period.”

[Class ends].

**Scalar and vector quantities**

This topic is in mechanics but students’ responses to some of the discussion questions touched on concepts they had already learnt in electricity. It was pointed out in chapter two that misconceptions in one domain of an analogy can be transferred to another domain or concept. Usually, if there is an error in the
analogue domain, it is highly likely that the same error will be transferred to the target domain (Duit, 1991). Contexts may be different, but the error is part of what shapes the new context. The excerpt below illustrates a situation where the teacher was discussing scalar and vector quantities in mechanics, from which students transferred misconceptions to electricity. Some misconceptions were detected during the following teacher-student dialogue:

**Teacher:** “What we have calculated is the rate of change of displacement.”

**Teacher:** “What is this called?”

**Student 1:** “Velocity”

**Teacher:** “Mmm--- correct. What kind of quantity is velocity?”

**Student 2:** “Vector quantity.”

**Teacher:** “Yes, give me some examples of vector quantities.”

**Student 3:** “Magnetic field.”

**Student 4:** “Voltage.”

**Teacher:** “Are you sure?”

**Student 4:** “Teacher, we say current moves because of potential difference between positive and negative terminals.”

**Student 5:** (Puts up his hand)

**Teacher:** “Yes.”

**Student 5:** “Weight.”
[There were many other correct responses from the other students but one of the students also suggested another concept from electricity].

**Student 6:** "Current."

**Teacher:** "But, we said voltage is not a vector quantity and therefore it follows that current is also not a vector quantity."

**Student 6:** "But sir, current flows from positive to negative and electrons move from negative to positive."

**Teacher:** "That's right. Let us revisit this question during the next lesson."

After the three topics were taught, all members of the Physics Department including the researcher, as already stated, designed the test that covered, among other things, the concepts that were taught using analogies. Since analogous concepts were mainly from electricity, only responses to items on electricity are presented and later analysed. Because the researcher was teaching one of the physics classes (not one of those in which the study took place), he was under an obligation to participate in the setting of the test. He deliberately sought inclusion of concepts that were taught using analogies. Therefore, the following question, which tested the understanding of the concepts taught analogously, was included:

"Explain what the following terms mean: electromotive force, current, resistance, back electromotive force, fuse, potential difference, variable resistor, constant resistor, open and closed circuit, and conventional current."
The majority of the students in the sample explained all the concepts except electromotive force, potential difference and back electromotive force. Using the marking scheme prepared by all members of the physics department (including the researcher) to score the test, it turned out that nearly all the students in the sample responded correctly to this question. But a significant number of students in the sample had difficulties with the concepts of electromotive force (emf), back emf (bemf) and potential difference (pd). The following definition of emf, bemf, and pd should be borne in mind if the reader is to appreciate the significance of the data produced by the students:

a) emf is the potential difference across the terminals of the cell when it is not producing current in a circuit.

b) when the emf of the power source drives a current through the direct current (dc) motor coil (see figure 4, page 111) at an angle to the magnetic field, motion is created. The coil turns. In the process of turning, the coil cuts through magnetic lines of force. This induces an emf. The induced emf, in turn, drives the induced current in the opposite direction to the source of current that started the motion of the coil. As a result, there is a tendency for the coil to “want” to move in the opposite direction. The induced emf is called back emf (bemf). Therefore, back emf is an induced emf that opposes the emf causing it.

c) Potential difference (pd) is the work done (in joules) when one unit of electricity (coulomb) moves from one point to another.
Understanding these definitions will enable the reader to examine students' definitions and explanations and to decide whether they present misconceptions or not, and to assess how far the students' responses deviate from the correct definitions.

Students' Alternative Frameworks: emf, bemf and pd

Although individual statements regarding back emf may vary from one another somewhat, the following general categories can still be discerned:

1. Those statements that depict bemf as held back/returning/ unused /helping emf.
2. Those statements that depict bemf as current/resistance/moving.
3. Those statements that depict emf and bemf as mechanical force.
4. Those statements that depict bemf as being in cells/accumulators.

The tables that follow show discerned categories of alternative frameworks.
Potential difference (Pd)

As in the preceding section, two categories of statements that convey alternative frameworks in defining Pd are created:

1. Those statements that depict pd as charge; and
2. Those statements that depict pd as current/resistance/moving.

Table 2: Students' Alternative Frameworks in Pd.

<table>
<thead>
<tr>
<th>Pd as charge</th>
<th>Pd as current/resistance/moving</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pd: This is the difference in charge between two terminals, which enables electric current to flow.</td>
<td>6. Pd: This is the emf flowing in opposite direction.</td>
</tr>
<tr>
<td>2. Pd: This is the difference in amounts of electrons between two points in an electric circuit which results in electron flow so that the two points have equal resistance.</td>
<td>7. Pd: This is the difference in current between two points in a circuit, [i.e., this may be due to resistors present in the circuit and voltage.]</td>
</tr>
<tr>
<td>3. Pd: This is the difference in quantity for example electrons in one place compared to another place.</td>
<td>8. Pd: This is the difference between the current from a source and the current getting to the load e.g. a battery of 1.5V has a pd of 1.5</td>
</tr>
<tr>
<td>4. Pd: It is the difference in charge between the power source and the rest of the circuit, which enables current to flow through the circuit.</td>
<td>9. Pd: This is the difference in the amount of current flowing in different resistors</td>
</tr>
<tr>
<td>5. Pd: This is the electrical difference between terminals, i.e. the difference in the number of electrons between the negative and positive terminals that allows current flow between terminals.</td>
<td>10. Pd: It refers to the resistance [experienced by] the flow of current in the circuit.</td>
</tr>
<tr>
<td></td>
<td>11. Pd: This is the difference in the amount of current at the ends of the conductor.</td>
</tr>
</tbody>
</table>
Table 1: Students' Alternative Frameworks in Emf / Bemf

<table>
<thead>
<tr>
<th>Bemf as unused/standby/ returning/ helping emf.</th>
<th>Bemf as current/resistance/ moving.</th>
<th>Emf and bemf as mechanical force.</th>
<th>Bemf as being inside the cells/ accumulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. bemf: Is an apparatus used when there is a shortage of current flow to help the appliance to continue working.</td>
<td>7. bemf: Is the emf which moves from the negative to positive round a complete circuit.</td>
<td>11. bemf: Is the force that helps to drive electrons across a circuit.</td>
<td>13. bemf: It is the emf due to the internal resistance of cells e.g. due to local action.</td>
</tr>
<tr>
<td>2. bemf: This is the voltage that goes back into the voltage source after going through the circuit</td>
<td>8. bemf: It refers to the flow of current against the flow of electrons.</td>
<td>12. bemf: This is the amount of force remaining after overcoming all the resistance in a circuit</td>
<td>14. bemf: This is the constant electromotive force in cells that enables current flow.</td>
</tr>
<tr>
<td>3. bemf: It is the emf which is got when you subtract the used-up emf from the source emf.</td>
<td>9. bemf: Amount of charge that [is] equal to the resistance offered to current as it flows from the source through a conductor.</td>
<td>15. bemf: This is the amount of electric energy that can be produced by an accumulator.</td>
<td></td>
</tr>
<tr>
<td>4. bemf: This is the amount of emf that goes back to the cell.</td>
<td>10. bemf: This is the resistance given to the movement of an electric current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. bemf: This is standby supply of electromotive force which helps current flow in a circuit in case the main supply fails.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. bemf: This is the force supplied in the circuit that helps in case of the main source supply failure.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conducting the analysis

According to Glesne and Peshkin (1982), working with the data, creating explanations, posing hypotheses, developing theories and linking one’s story to other stories is what analysis of qualitative data involves. To do this requires that one synthesises, searches for patterns and interprets the data that has been collected (Erickson, 1986). Early analysis revealed the difficulty of capturing gestural messages by the students and teachers. This realisation prompted the researcher to repeatedly view and listen to the visual and audio recordings in order to gain an accurate description of events. As the study progressed, the researcher used the methods below to keep record and track of events:

- Writing memos,
- Developing analytic files,
- Use of coding system as a way of sorting out data into analytic files,
- Compiling weekly reports as a way of managing the data collection process (Glesne & Peshkin, 1982).

Memo writing

This involved keeping a field notebook of reflections on what was being observed in every lesson. This was in line with the advice given by Glesne and Peshkin (1982):

Even as you become intimately familiar with your data, you can never be sure of what they will tell you until analysis and writing are complete. As you work with data, you must remain open to new perspectives, new thoughts. (p.129)
In other words, all reflections and thoughts made as the collection of data progressed, remained tentative (always expecting new thoughts, interpretations, and conclusions) until the final report was written.

The files grew as the study progressed. The data thus collected determined the nature of the analytic files and the corresponding coding system. The researcher considered this exercise a learning experience as well as research.

Glesne and Peshkin (1982) support this by saying:

Understanding that you are in a learning mode is most important; it tells you that you need not be all at once as accomplished as eventually you need to be to meet the challenge of data analysis. It reminds you that by each effort of data analysis, you enhance your capacity to further analyze. (p. 129)

In conducting the final analysis, the Erickson’s (1986, p. 145) nine point guidelines were used, and complemented by several other guidelines that the researcher considered appropriate:

1. **Generating and testing empirical assertions**

   This involves analysing the data with the aim of generating assertions by searching through the data corpus. It also involves establishing evidential warrants for whatever assertions emerge or get generated (see the section on inferences and assertions).

2. **Analytic narrative vignettes**

   This involves a vivid portrayal of the conduct of events of everyday life: insights and sounds of what was said and done are described in the natural sequence of their occurrence in real time. The dialogical style of
description enables the readers to feel as though they were there.

The following were used in support of inferences:

3. *Quotations from observation notes*

4. *Quotations from interviews*

5. *Symbolic data reports* (e.g. maps, frequency tables, figures)

6. *Interpretive commentary* framing particular descriptions. These are presented in various ways including:

   (i) Interpretation that isolates and follows an instance of particular description in the book,

   (ii) Theoretical discussion that points to the more general significance of the patterns identified in the events that have been reported,

   (iii) an account of the changes that occurred in the researcher’s point of view during the course of the inquiry.

7. *Interpretive commentary framing general descriptions*

   The main function of reporting general descriptive data is to establish the generalisability of patterns that are illustrated in a particular description through analytic vignettes and direct quotes from observation and interviews:

8. *Theoretical discussion*

   This involves grounding the findings in theory and pre-existing literature.

9. *Natural history of the inquiry (see the methodology chapter four).*

   It should be pointed out that there is no clear-cut line between some of these steps. In addition, these are not the only guidelines that were followed; the
researcher's creative insights and understanding of events represented by the data are very important and have played a part in generating the inferences and assertions from the data which are discussed later in this chapter.

Context of the Analogies

This section discusses the context in which each of the 20 analogies in table 1 were captured during the 14-week classroom observation. In some cases, portions of excerpts of the discussions in which the analogies were located are provided as a way of presenting the reader with a picture of the events involving the analogies. This also gives the reader a feel for the discussion and the evolution of the analogies during instruction.

Analogy 1S: Magnetic effect of electric current

In a lesson on “Magnetic effect of an electric current,” the teacher discussed the effect of current on a current-carrying solenoid. How the strength of the effect can be increased or maximised was one of the points discussed. Several ways of increasing or decreasing the magnetic effect of a current-carrying solenoid were discussed, including:

(i) increasing the number of coils (turns),

(ii) increasing the current,

(iii) placing a soft iron bar inside the solenoid.

The teacher explained (iii) by indicating what the function of the soft iron bar is. He told the students that the purpose of the soft iron is to “concentrate”
magnetism. Clarifying this point further, the teacher compared the function of the iron bar to the process of “limiting the operation of students so that they do not stray”. Straying means going off course, and for magnetism to stray, it means that its effect is directed to unwanted places. To direct it to the desired area, an iron bar is used so that the magnetism is concentrated in one region.

_Analogy 2S: Electromagnets_

Discussing the section on electromagnets, the same teacher, S, discussed the requirements for creating an electromagnet. Apart from the insulated wire and the soft iron bar, a direct current (dc) is necessary. At this point the teacher also discussed the various sources of dc. But, he told the students that they could not use the current from the mains because it is an alternating current (ac). However, he told the students that ac can be transformed to dc using rectifiers. He compared the rectification process to “helping students who always have problems with the school rules acquire good behaviour”.

The analogue of putting students’ behaviour on the right course when they keep alternating between bad and good behaviour, i.e. rectifying behaviour, was compared with rectification of ac. Behaviour management is common to these students, since they are all boarders and necessarily have many rules to obey. There are many school rules, class rules, dormitory rules, home rules, club rules and even parental rules. This can be difficult for some of the students to cope with. Those who break the rules get punished in one way or another. The purpose
of the punishment is to *rectify or correct* the behaviour to what the established rules define.

*Analogy 3T and 4T: Circuits and current*

Two analogies were detected during a discussion of simple circuits, 3T and 4T. Potential difference was explained using the idea of *raising a stone above the ground*. Its potential energy varies depending on its height above the ground. The ground being at zero potential energy, the stone can only fall when there is a potential energy difference between its original position and the ground. This was compared to potential difference across a bulb. The teacher did not go into the details of matching the attributes (Harrison & Treagust, 1993). He only said, “If the potential difference is high the brighter the bulb” (3T).

The idea of cells as sources of electric current was mentioned but the focus was on the cells as sources of electromotive force (emf). The teacher compared emf to a mechanical force that causes motion: “Force causes motion. Similarly, electromotive force causes the electrons to move” (4T).

*Analogy 5T: Electromotive force*

There was not much comparison between emf and mechanical force that causes motion. The teacher must have assumed that the message was clear. However, one can clearly see gaps in the relationship. For example, force causes the motion of what? We note here a compartmentalisation of issues or ideas in the explanation. Electromotive force was explained independently of pd. One of the students thus appeared confused.
Student: “How does emf differ from pd?”

Teacher: “emf is for a cell and pd is for across the resistor. Common to emf and pd [is] the unit of measurement, volt. Just as work and energy are measured in joules” (5T).

Analogy 6T: Sources of electric current - cells

As a continuation of the same lesson, the teacher introduced the topic: “Sources of electric current - the cell”. This lesson focused on a simple cell. The idea of zinc metal (rod) always releasing electrons to the copper was viewed in terms of generosity. This release of electrons and acceptance of them by the copper rod was compared to what teacher T referred to as “Some men’s willingness to give while others do not give easily.”

The teacher in one of the classes completed the circuit in a class demonstration showing zinc metal dissolving fast into the electrolyte. This happened when he made a connection between copper and zinc rods. The teacher then measured the potential difference between copper and zinc as 1.0 volt and said, “This is how much zinc is willing to give to copper. The willingness of zinc to give electrons generates a current.” The reaction was then represented on the chalkboard by the following equation:

\[ \text{Zn}(s) \rightarrow \text{Zn}^{2+}(aq) + 2e^- \]

Just to reinforce the fact that copper is the recipient and zinc the donor, the teacher said: “The electrons become visitors of copper. We are going to talk of these friends of copper”. By “visitors” and “friends”, the teacher meant electrons.
Analogy 7T: Simple cells

The lesson that followed was about the defects of a simple cell. The teacher focused the discussion on what happens at the copper electrode in a simple cell. He wrote the following equation on the chalkboard to explain what happens at the copper electrode:

\[ 2e^- + 2H^+(aq) \rightarrow H_2(g). \]

Referring to the chemical equation, the teacher reminded the students of where the \( 2e^- \) and \( 2H^+ \) come from. He told them that \( 2e^- \) are the two electrons donated by Zinc, while \( 2H^+ \) came from the acid in which the Copper and Zinc rods are placed.

The teacher then pointed out to the students that the formation of hydrogen at the copper electrode affected the continued operation of the cell. He told them that the hydrogen gas produced at the copper electrode is a poor conductor of electricity and, therefore, insulates the copper electrode. He told the students that this effect is called polarisation. The teacher then compared polarisation to the separation of girls and boys in a mixed boarding school, saying:

"In a mixed boarding school, boys and girls are prevented from mixing outside their classes by building fences around their residences".

This had the implicit meaning of Copper and Zinc being equated to girls and boys. It was not clear specifically which one, copper or zinc, represented boys and which represented girls. Discussing how one can eliminate polarisation, the teacher suggested the use of manganese dioxide as one of the depolarisers. He compared depolarisation to the removal of the separating fences around the residences of the girls and boys to re-establish contact (7T).
Analogy 8S: Heating effect of electric current

In a lesson on the “Heating effect of an electric current” the teacher explained the principle of conservation of energy and how it applied to current. He gave the immersion heater, electric cooker, electric kettle and iron boxes as examples of devices that convert current (electricity) to heat. The teacher further discussed with the students the consequences of using excessive current. At this point the teacher discussed with the students precautionary measures that can be taken to prevent damage to these expensive devices, including the use of a fuse. He inquired from the class about their experience of fuses, especially what happens to them if excess current is used. Students used various phrases that described their experiences, for example, blowing up, burning, spoilt and smoking of the fuses. The teacher agreed with the students’ terminology and told them:

“Fuses are wires of low melting points. When current is excessive, the fuse melts breaking the circuit”.

He then provided the students with a mathematical relationship between heat, current, resistance and time:

“Heat is proportional to current squared times resistance times time.” This was written in symbolic form as well.

\[ H \propto R I^2 t \text{ or } H = I^2 R t \]

From the equation, the teacher showed how the variation in current could affect the appliance or any other electric appliance. He said, “Fuses are inserted in circuits to prevent damage occurring to electric appliances”. He explained how
a fuse functions by comparing it to a Presidential bodyguard: “A fuse is like a Presidential bodyguard who no matter what, has to protect the President to the extent of even putting his life on the line in defence of the President” (8S).

Here, what the teacher meant was that the function of the fuse is to protect the appliance to which it is connected. In case of excess current, it melts, smokes, blows, or gets destroyed, thus disconnecting the circuit before the appliance gets damaged.

Analogies 9W, 10W and 11W: Primary and secondary cells

Analogies 9W, 10W and 11W were used by teacher W in a double lesson in which the ideas of current, resistance and potential difference were discussed. Although these ideas were discussed in the same lesson, there was no attempt to present the concepts in the form of Ohm’s law. The lesson started with a discussion about a dry Laclanche’ cell as the source of emf. The teacher asked the following questions:

"Why is manganese dioxide close to the carbon rod?"

“What are some of the changes that occur after the cell is used?”

One of the students responded to the second question by saying:

Student: “It becomes a little bit softer.”

Teacher: “Why?”

Student: “The hydrogen gas produced makes it so.” (see page 114).

Teacher: “Probably. Do you think there is water?”

The dialogue continued up to a point where the teacher introduced the idea of secondary cells. He told the students that the reaction in primary cells, such as the simple cells, is irreversible, but the reaction in secondary cells is reversible. A
student interrupted, changing the nature of the discussion as follows:

**Student:** “Before cells are used in radios, some people wrap them in polythene paper. Why?”

**Teacher:** “To prevent the solution from leaking onto the terminals.”

**Student:** “Does it mean that current will flow through a polythene paper?”

The teacher explained by drawing a sketch of the wrapped cell on the chalkboard. At this point, the idea of a battery was introduced.

**Teacher:** “A combination of cells makes a battery. Which direction does current flow? In geography we talk of water current, air current, and so on. What is water or air current? Water current is the movement of water from one region to another. Similarly, electric current is movement of electrons from negative to positive” (9W).

During the next lesson, teacher W continued with the discussion about secondary cells or batteries. Charging and discharging of secondary cells was discussed in detail. Students showed a lot of interest in this particular topic. The teacher drew a sketch of a water tank on the chalkboard (see figure 1, page 104), showing how it is drained and refilled with water (11W). He compared it to the charging and discharging of accumulators in cars.

**Teacher:** “An accumulator is like a water tank. Opening the outlet tap is like discharging the accumulator. After draining the tank of water, it can be refilled. [This] is similar to recharging of the accumulator” (11W).

During the lesson, the concept of conventional current was explained. This time the teacher compared conventional current to the relative movement of
roadside objects as seen from inside a moving vehicle (10W):

"When a vehicle is moving along a road, observers inside the vehicle see electricity posts, telephone posts, trees and so on, on the side of the road moving in the opposite direction to the vehicle" (10W).

Revisiting the idea of recharging an accumulator, the teacher explained how the process of recharging a battery is different from refilling a water tank.

This was like identification of dissimilar attributes (Glynn, 1991; Harrison & Tregast, 1993; Zeitoun, 1984). The teacher then said: "During refilling, we do not refill through the discharge tap, unlike the accumulator" (11W).

Of course, not everything was explicitly compared. Because the analogues were familiar to the students, the teacher probably assumed that the rest, i.e., the dissimilar attributes, were easy to identify and therefore never completed the list of dissimilar attributes.

*Analogy 12S: Secondary cells*

More details about the water tank-accumulator analogy was provided by teacher S. For example, the effect of leaving a battery in a discharged condition for a long time was compared to the effect of leaving an empty metallic water tank for a long time. He said: "If the accumulator is completely discharged for a long time, white crystalline lead sulphate forms and cannot be reversed for recharging. Similarly, if a metallic water tank is left empty for a long time, it rusts and may no longer store any water" (12S). This comparison is a kind of attribute match. However, the match is not complete. A rusty water tank can still store water, except when it is leaking. The teacher should have pointed out this factual
mismatch or related the effect of rusting to human welfare, whereby water in rusty containers can not be safely consumed. The suspicion is that teacher S may have been thinking along these lines and assumed it to be obvious to the students. Again, the teacher particularly referred to the metallic water tank but not to a concrete or a plastic water tank. Plastic water tanks are now common in Kenya. They are a way out of the problem of rusting or mould growth in empty concrete water tanks. Nonetheless, refilling and emptying a metallic water tank was compared to the discharging and recharging of an accumulator and the comparison of respective consequences of leaving the water tank and accumulator in a discharged state for a long time, seemed to match.

*Analogies 13T, 14T and 15T: Electrons and current*

A lesson on alkaline cells contained several analogies. The teacher explained to the students that nickel hydroxide\(^6\) is the positive electrode while cadmium is the negative electrode:

**Teacher:**

"Nickel can receive electrons but can not give out electrons. Nickel ions have already given out electrons and can no longer give out more. It says, I have already given out what I can and no more. But I can take in electrons."

The teacher then compared this to a person who donates generously until he/she can no longer give/donate.

---

\(^6\)Nickel hydroxide is in powder form and it is the active material enclosed in perforated pockets in specially constructed steel plates. The container in which the electrolyte (sodium or potassium hydroxide) and the electrodes (nickel hydroxide and cadmium) are enclosed is made of nickel-plated steel (Abbott, 1984, p. 402).
Teacher: “This is similar to a person who gives out all he or she can until he/she becomes in need” (13T).

A discussion of the advantages and disadvantages of alkaline cells concluded the lesson. Realising that there was still time before the lesson ended the teacher introduced a new topic current. It should be noted that, this was the second time the topic “current” was being discussed, but in a review form. The following dialogue reveals some analogies that were used:

Teacher: “What is an electric current.”

Student: “A flow of electrons in a circuit.”

Student: “Flow of charge”.

Teacher: “I disagree.”

Student: “Amount of electrons that flow through a conductor

Teacher: “So if ten electrons flow, then that is current? The electrons flow from negative terminal to positive terminal. Now what is current?

Teacher: “If we talk of electric current, it means we have other currents. What are they?”

Student: “Conventional Current”

Teacher: “That is still electric current, isn’t it?”

Student: “Air Current”

The teacher then provided the details of situations that lead to current flow. He compared current, current flow and conditions leading to current flow, to those of water and wind.

Teacher: “When a river is flowing we have a current developed. There is
something common to all currents” (14T).

The teacher again cited several situations in which current is said to flow. At this point, he explained the target idea – current – using several analogues.

Teacher: “Wind flows from a high pressure zone to a low pressure zone, that is, from say, point G to point H. What is the difference in G and H?”

Students: [all quiet].

Teacher: “Something similar to diffusion, isn’t it?”

Students: [students fuddled by the look of their faces; suggesting discomfort].

Teacher: “Flowing from a region of high concentration to a region of low concentration. Similarly, a river flows from a region of high altitude to a region of low altitude. The difference in altitude causes river flow. High altitude is compared to high potential. The electric current follows the same pattern. The terminals are at different potential. We agreed that positive was masculine and negative was feminine. Thus, current flows from positive to negative. This is the same current we call electric current” (15T).

This episode contains several analogies. For example, potential difference is compared to the difference in altitude. Altitude difference is in turn compared to concentration difference that leads to diffusion. Here, an analogy is used to clarify other targets: current flow, potential and potential difference. In a follow-up lesson, the teacher explained to the students the flow of current. He explained how current flows from positive to negative using an analogue that had a gender connotation.
Teacher: “We agreed that positive was masculine and negative was feminine. Thus, conventional current flows from positive to negative. If there is no difference in potential, we have a problem. No current flows. The giver must ensure he gives” (15T).

Again, this episode contains a number of analogues. However, despite its negative implications for gender equity, the key purpose was to compare the roles of the positive electrode in current flow to masculine roles in human interaction. It is not easy to identify masculine features that match the positive electrode features. Similarly, one wonders what feminine features match the negative electrode features. However, the teacher comes out with masculine roles in the last statement that sheds light on the nature of the comparison: “The giver must ensure he gives”. “He” represents masculine. The statement may be perceived to imply that it is the duty of men to give. In addition, the message one gets is that women must receive. However, without taking it out of context, this is an example of an incomplete or simple analogy which requires further development (see Dagher, 1995).

Analogy 17T: The effect of magnetic field on a current-carrying conductor

A brief explanation of direct current (dc) was given and the idea of a dc motor was introduced. A dc motor operates on the principle of magnetic effect on a current-carrying conductor. When a current-carrying conductor is placed in a magnetic field, motion of the conductor is generated as a result of the interaction between two magnetic fields. As the wire moves, “cutting” through the magnet’s magnetic field, current is generated or induced. The generated (induced) current
moves in the opposite direction to the one causing the movement of the conductor. Current movement is caused by an emf. Induced emf causes current to move in the opposite direction to the initial current that caused the conductor to move. Because the induced current moves in the direction opposite to the "input" current, the corresponding induced emf causing the induction of current gets the name back emf (bemf). The teacher compared bemf to friction.

**Teacher:** "When a car is moving, it experiences a back opposing force called friction. Friction has to be overcome in order for the car to continue moving. Similarly in a dc motor, the back emf ... has to be overcome for the coil to continuously rotate when current is passing" (17T).

In this episode, the teacher attributed the jerky effect experienced in a dc motor, especially when starting, to the back emf. He therefore attributed the opposition to the coil movement in a dc motor to the induced emf, which causes induced current to flow in the reverse direction. The focus in this analogy is on the "resistance", which has to be overcome. The causes of friction and emf were not compared. This is an example of "mono-attributal" analogies, only one attribute in the analogue is similar to only one attribute in the target.

**Analogy 20T: Couple of forces**

This was another gender-related analogy. It was used to explain the concept of a couple of forces. The dc motor circuit was again used to explain this concept. Two kinds of forces act on the coil in the dc motor in order for the motion or rotation to occur continuously. These forces act in the same direction (clockwise or anti-clockwise). In figure 4 (page 111), which represents a sketch
of a dc motor circuit in a magnetic field of a curved magnet, the side ab of the coil is moved upwards while at the same time cd is moved downwards. These directions are determined using Fleming’s Left Hand Rule (motor rule), which the teacher stated and wrote on the chalkboard.

Fleming’s Left Hand Rule (Motor Rule):

Place the forefinger, second finger, and the thumb of the left hand mutually at right angles. Then, if the Forefinger points in the direction of the Field and the second finger in the direction of Current, the thumb will point in the direction of Motion (Abbott, 1984, p.436).

The forces of equal magnitude act on ab and cd. Since they act in the same direction, they form a couple. The generated analogy shows how the teacher used the students’ understanding of a “couple” to explain what a “couple of forces” is. In the analogy (20T) the students know a “couple” as a man and a woman. But the teacher makes it clear that the man and the woman must be married before he used it to explain the target concept – couple of forces. In a way, the teacher observed what Duit (1991) recommends as the norm in using analogies – making sure that the students and the teacher have a common understanding of the analogue.

Teacher: “What is a couple in a life situation?”

The analogue in the episode (20T) is not generated by the teacher, instead it is supplied by a student. The student compared two forces to a married man and woman. There is an implicit idea of acting together or something linking the forces. They are not just ordinary forces. While the forces are “linked by the coil”, the man and woman are “linked by marriage”. The students had probably been
converted to the teacher's way of "analogising" animistically and humanistically. Pittman (1999) considers this as a way of students revealing their understanding of such a concept. For this reason he proposes student-generated analogies as a way of formatively assessing their deeper understanding of target concepts.

**Student supplied analogies**

_Analogy 16S: Fuses_

The discussion was about protecting electric appliances. To achieve this, the teacher told the students that a fuse is used. The teacher further explained to the students why and where fuses are connected on appliances, such as electric kettle plugs. Other appliances such as radios, computers, irons, cookers, and drilling machines, all of which use electricity, were discussed. But how the fuse works was the source of the current analogies that have been grouped as 16S because they all explain the function of the fuse. The teacher stated "A fuse protects electric appliances. Its purpose is to safeguard another component. It melts, and that is the end of its life". These last two sentences are the ones explained by the Presidential bodyguard analogue. The teacher asked the students to provide daily experiences that functioned like fuses. This is one way Pittman (1999) says that students' understanding can be evaluated — having them generate analogies. The dialogue below contains student-generated analogies in response to teacher's question about fuses:

**Teacher:** "Who can give us a daily experience that would function like a fuse?"

**Student 1:** "Like in school life, one sacrifices student time to achieve higher."
**Student 2:** "In school life you can be given an option of kneeling down or get strokes. You sacrifice your pride by accepting strokes in order to continue with school."

**Student 3:** "An employee who is asked to do an inhuman job for less salary opts for a sack than to put his dignity on the line." (not to jeopardise his/her standing in society)."

The analogies contained in the above student responses mirror the teacher's real life experience analogue – the function of the Presidential bodyguard to explain the functions of the fuse. The way the teacher's question was framed and the kind of analogue he initiated earlier, influenced the students’ choice of analogues (see Pittman, 1999). All the analogues had something to do with humanism and cultural context.

**Analogy 18W: Resistors**

In an interview with students, the researcher asked them to explain how variable and constant resistors work.

**Researcher:** "Tell me how variable and constant resistors work?"

**Student M:** "Peer pressure. Peers usually endeavour to oppose a decision they don’t like. If you do not stay firm in your decision."

Here, it appeared the student was explaining a variable resistor. He compared it to the pressure peers exert on colleagues. This pressure varies. It keeps on increasing. The student suggests that this pressure can be unbearable: If one does not stay firm, it is possible to give in to peer pressure. Such pressure may for example, be “drug abuse” or some other undesirable peer behaviour.

**Student N:** "In a river flow, an obstacle like a stone would oppose its flow."
In this analogy, the student is comparing a constant resistor to an obstacle such as a stone, which does not change to any great extent the amount of resistance it offers to river flow. Even if the amount of water in the river is increased, the opposition by the obstacle, the stone, remains constant.

This same student compared a variable resistor to what athletes encounter: “In athletics, other runners always try to stop you from running to win.” Perhaps to reveal more about student N, without violating the confidentiality of identity, I should point out that he comes from an athletic community in the Rift Valley province. This community has produced some of the world’s best long distance runners, making Kenya one of the world’s top producers of the outstanding long distance runners. In this case, this student has provided an analogue he understands very well. It is a fact that athletes try to compete against each other for a place in, say, the Kenya Olympics team. It is possible that in a tense situation athletes attempt to stop each other from winning. This effort does vary as one gets tired. It then compares with a variable resistor.

**Student P**: “Like prefects always oppose wrong doing, no matter what. Their opposition is the same.”

This student compared a constant resistor to a conservative or firm stance taken by prefects. They are not flexible. This inflexibility is viewed as constant. As long as it is a wrong doing, the prefect’s stance is the same. This was the only student who also used a scientific analogue to explain a constant resistor: “Like charges opposing each other.” This phrase is in the same context as the one about prefects. There is no time that like charges can compromise and attract; they will always repel.
Students Q and R focused their attention on to the prevailing road situation in Kenya.

**Student Q:** "Accidents on the road would not allow the smooth movement of traffic."

In this statement, one gets the sense of fixedness and variability of resistance. The statement serves dual purposes. If the accident brings traffic movement to a halt or a very slow movement for a long time, then the situation may be compared to a constant resistor. Nevertheless, if the accident causes a sudden slow and fast movement of traffic, then the situation compares to a variable resistor.

**Student R:** "A pothole on the road would interfere with the smooth running of vehicles."

This student is generally comparing the effect a pothole on the road can have on running water or vehicles. The effect does not change. It is constant. It impedes water flow or vehicle movement. This situation compares with a constant resistor. This analogous situation is part of the environment in which the school is located.

At the time of the study, roads in the neighbourhood of the school had many potholes. The experience was that movement of traffic was hindered by the poor state of the roads. The following was the teacher’s version of the explanation of variable and constant resistors:

"Athletes always experience resistance from wind that flows in the opposite direction … Consider water in the tank and [an] outlet pipe at the bottom … The size [of the pipe] determines the amount of water let out."

It is possible that the teacher closely followed the students’ responses and provided his response in the same context. However, in the teacher’s case, athletes do not oppose counterparts. They are opposed by wind. Wind blows in
the opposite direction. This retards an athlete's movement. The retardation keeps on varying. The wind situation in this case is compared to a variable resistor.

The teacher also compared resistance to the size of the outlet pipe of a water tank. The size determines how much water is let out per unit time. If the tank has a gate valve, then the outlet size can be varied. This compares to a variable resistor. But if the outlet pipe has no gate valve, then the water let out per unit time does not vary. In this case, it is compared to a constant resistor.

*Analogy 19W: Ohms law*

The last lesson on electricity by teacher W was about water-flow analogy as recommended by the syllabus. The teacher modified the standard water flow diagram used in standard textbooks (see figure 1, page 105)

**Teacher:** “An object at a higher place drops to a lower place. Why?”

**Student:** “Because of potential energy.”

**Teacher:** “The body experiences potential energy difference. Similarly, the water in the tank flows due to the potential energy difference of the water column.”

The teacher then explained this situation by making a concluding statement regarding stoppage of water flow.

**Teacher:** “When the heights are the same, the energy difference is zero, hence the movement of water stops. What would behave in a similar manner in an electric circuit?”

**Student:** “The electromotive force.”

**Teacher:** “What is the role of the pipe?”

**Student:** “Conductor.”
Teacher: “What other functions does the pipe have in this arrangement? Wide and narrow pipes, which one will deliver more water?”

Student: “The wider.”

Teacher: “What can we equate the pipe to in the electric circuit?”

Student: “Resistor.”

Teacher: “What about the tap?”

Student: “The switch.”

Teacher: “The lower the resistance the higher the current and vice versa.”

At this stage the teacher drew a sketch of the pipe and marked the points X and Y (see figure 2, page 110). He compared the pipe to an electric wire conductor. The discussion developed as follows:

Teacher: “Why does water flow from one point X to another point Y?”

Student: “Pressure”

Teacher: “Yes, pressure difference leads to a water current. Similarly, current flows due to a potential difference.”

After this lesson, the researcher had an informal follow-up interview with the teacher.

Researcher: “Why did you use potential energy instead of pressure in your water flow analogy?”

Teacher: “My experience is that when I use pressure in water tanks, the students are not convinced that the cell exerts pressure. But when I use energy, from their knowledge of chemical energy conversion to electrical energy, they get convinced.”
Researcher: “And why did you use two water tanks as opposed to the circulatory flow diagram that most people use?” (See figures 3a, 3b, page 110 and 5a, page 157).

Teacher: “I have found that I can explain everything in an electric circuit using my diagram [(see figure 5a, page 157)]. The water circuit diagram is difficult because it doesn’t explain well. Again, when we are solving problems, a pump is considered a resistor and yet here, it is providing emf. The students get confused.”

From this episode, the teachers’ and students’ views and intentions can be discerned. The purpose of describing the whole as opposed to separating it into two parts—analogue and target, is to enable the reader to follow and appreciate the development of the analogy.

It is hoped that this section has provided the reader with the context in which the analogies described were captured. The next section discusses how each analogy fits into WWA model structure.

**WWA Model and the Case Study Analogies**

Since analogies are predominantly used as instructional tools for concepts that are abstract in nature, it is important that they be systematically developed and used in teaching. In chapter two, the GMAT and TWA models were discussed and WWA was presented as a derivative model of these two. This new model is used in examining the completeness of the 20 analogies discussed above. WWA model comprises six stages against which the analogies are checked to ascertain their completeness and suitability. Table 3, below, shows which WWA stages were observed by the teachers and students in constructing the analogies.
Table 3: Comparing analogies with WWA

<table>
<thead>
<tr>
<th>Stages of WWA</th>
<th>Analogy</th>
<th>Analogue(s)</th>
<th>Target(s)(s)</th>
<th>Comment(s)</th>
</tr>
</thead>
</table>
| 1. Assess students’ knowledge of analogue. | 12S | Causes of rusting. | Causes of formation of crystalline lead sulphate on lead plates in lead-acid battery | - Teacher established context in which metallic tank rusts by asking students related questions.  
- Questions tested students’ knowledge of analogues.  
- The teacher then transferred this knowledge to the target domain. |
<p>| | 14T | Pressure difference causes wind flow. | Electric current flows due to potential difference. | - In this analogy, a set of analogues are used to explain similar analogues before being transferred into the target domain. |
| | 16S | Functions of a Presidential bodyguard. | Function of electric fuse | - Students generate analogues to explain how a fuse works. No knowledge of analogue is directly sought but intention clear, i.e., own analogues exposed own preconceptions. |</p>
<table>
<thead>
<tr>
<th>Stages of WWA</th>
<th>Analogy</th>
<th>Analogue(s)</th>
<th>Target(s)</th>
<th>Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19W</td>
<td>Pressure difference causes water to flow in a pipe.</td>
<td>Ohm's Law.</td>
<td>• The teacher discussed with the students how pressure difference between two points in a pipe of water (see figure 2, page 109) leads to water flow. The knowledge of the analogue was established before being used to explain the relationship between current, potential difference and resistance. The teacher in a way established students' knowledge of analogues and transferred to the target – in compliance with stage 6 of WWA.</td>
<td></td>
</tr>
<tr>
<td>20T</td>
<td>A married couple (man and woman).</td>
<td>Couple of forces.</td>
<td>• The teacher asked the students to explain the meaning of a couple. This was in direct compliance with step 1 of WWA. He further clarifies the kind of couple that he is going to use to explain the target.</td>
<td></td>
</tr>
<tr>
<td>Stages of WWA</td>
<td>Analogy</td>
<td>Analogue(s)</td>
<td>Target(s)</td>
<td>Comment(s)</td>
</tr>
<tr>
<td>----------------------------</td>
<td>---------</td>
<td>-------------------------------------------------</td>
<td>------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2. Assess students’</td>
<td></td>
<td></td>
<td></td>
<td>• No attempt to assess target knowledge made in all the 20 analogies.</td>
</tr>
<tr>
<td>knowledge of target.</td>
<td></td>
<td></td>
<td></td>
<td>• Mostly a statement was made holistically, especially in cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>where there was no attribute mapping (e.g., 1S, 4T).</td>
</tr>
<tr>
<td>3. Identify analogue</td>
<td>12S</td>
<td>Rust formation on empty metallic water tanks.</td>
<td>Formation of white crystalline lead sulphate on</td>
<td>• No direct attempt to identify analogue and target attributes in</td>
</tr>
<tr>
<td>and target attributes</td>
<td></td>
<td></td>
<td>lead plates in discharged lead-acid battery.</td>
<td>all the 20 analogies except in 12S and 15T.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• There was implicit identification of attributes in 12S when</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>the teacher used similar questions to elicit students’</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>knowledge of analogue and target.</td>
</tr>
<tr>
<td>Stages of WWA</td>
<td>Analogy</td>
<td>Analogue(s)</td>
<td>Target(s)</td>
<td>Comment(s)</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------</td>
<td>-------------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4. Map similar</td>
<td>15T</td>
<td>All</td>
<td></td>
<td>• The teacher points out attributes in the analogue and target by stating what masculine in the analogue corresponds to in the target – positive terminal, and what feminine in analogue corresponds to in the target – negative terminal. The implicit message is that the “act of giving” as an attribute in the analogue, corresponds to the current flow in the target domain.</td>
</tr>
<tr>
<td>attributes</td>
<td></td>
<td></td>
<td></td>
<td>• The teachers mapped similar attributes in analogue-target domains simultaneously with stage 6, that is drawing conclusions. In other words, these two stages were not separated.</td>
</tr>
<tr>
<td>Stages of WWA</td>
<td>Analogy</td>
<td>Analogue(s)</td>
<td>Target(s)</td>
<td>Comment(s)</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>---------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5. Identifying</td>
<td>11W</td>
<td>A metallic water tank</td>
<td>An accumulator</td>
<td>• No attempt to point out unmapped attributes except in 11W.</td>
</tr>
<tr>
<td>mismatching or unmapped attributes.</td>
<td></td>
<td></td>
<td></td>
<td>• In 11W, the teacher points out unmapped attributes by directly pointing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>out contrasting features.</td>
</tr>
<tr>
<td>6. Draw conclusions</td>
<td></td>
<td>All</td>
<td></td>
<td>• See stage 4</td>
</tr>
<tr>
<td>about the target</td>
<td></td>
<td></td>
<td></td>
<td>• Mapping similar attributes and drawing conclusions about the target</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>were not separated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• In some cases, target conclusions were done implicitly.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• The teachers probably assumed that such conclusions were logically</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>obvious.</td>
</tr>
</tbody>
</table>
Generally, the analogies were characterised by the transfer of whole analogue meaning to the target. In some of the analogies, the meaning of a target was clarified by referring to the analogue holistically. This approach prompted the researcher, in some cases, to describe the whole episode in order to provide the reader with the context of the analogy used. In other cases, there was a very thin line separating the whole analogue/target mapping from individual attribute mapping.

The WWA model aims at providing a systematic framework for developing and using analogies meaningfully and rationally. However, in all the analogies observed in the study, at least one of the steps in WWA was not addressed. The missing steps varied from one analogy to another. Stage 2, Assess Students’ Knowledge of target, was absent in most analogies. The assumption may probably have been that the students had no knowledge of the target at all. This should not be assumed to be always the case because students have already developed ideas of their own about some of the phenomena or experiences before the lesson even begins (Driver, 1983).

Analogies 18W and 19W have not been analysed using WWA because they were generated during a follow-up interview. They were dependent on the questions the researcher asked and furthermore, whose purpose was to seek clarification of what had already been discussed in class.

The section that follows presents and discusses important inferences from the 20 analogies. In addition, possible students’ alternative frameworks are discussed.
Inferences and Assertions

The Nature of analogies

Analogy use depended on the teacher, the extent of conceptual abstraction, the level of difficulty of the concepts to be explained and the nature of the class composition. For example, most analogies were in the area of electricity, probably due to the abstract nature of the concepts associated with the topic. As Duit (1991) says, "...many analogies facilitate a visualisation of abstract domain". In addition, they make new information more concrete and easier to imagine (Shapiro, 1985 cited in Duit, 1991; Kelly, 1955).

There is strong evidence that the teachers drew their analogues from students’ daily experiences. These were environmental (cultural) and humanised life experiences. The African view of nature is anthropomorphic, which is in direct opposition to the western, mechanised perception of human nature (Jegede, 1995). In Jegede's words, "The world, to the African, is full of 'life' with every entity having its own type" (p.109). This is further exemplified by the fact that the African sees everything as having life (Jegede, 1995). Typical of this were occasions in this study in which the teachers presented "in-animates" as though they were talking. For example, 6T - "zinc is willing to give copper...", "The electrons become visitors of copper..", "...we are going to talk about those friends of copper" and 13T - "It says, I have given out what I could and no more, but I can take in electrons".

However, there are exceptions: there are those people in present Africa
who have changed their traditional styles of living and even get offended when they get “lumped” together with those who hold traditional views. Furthermore, illustrating the processes of abstraction this way may not be confined to Africans. Statements like those above are common among British teachers who refer to sodium, say, as trying to get rid of an electron and magnesium as being “even more generous” and wanting to get rid of or donate two electrons. Chlorine is considered “happy” if it can gain an electron and achieve a noble gas configuration. Perhaps this way of teaching is what Watts and Bentley (1994) have in mind when they advocate research into animistic and humanistic teaching of science because of the “observed comfort” for the students it produces.

Analogues from students’ existing or prior scientific knowledge were used except when the existing scientific knowledge was related to a life experience such as friction. Friction was used to explain back emf in a dc motor and the knowledge of a water tank system was used to explain the idea of emf and pd. This has an implicit agreement with what Jegede (1995) calls the African’s love for the environment. The concept of friction is more connected to humans than, say, the concept of upthrust. This is consistent with the fact that “The starting point for all these activities [(teaching and learning)] “... should be the pupils’ own [cultural] environment and experience ...” (Prophet, 1990, p.16).

Teachers avoided using existing scientific analogues for fear of creating confusion in students. For example, one of the participating teachers used potential energy instead of pressure to explain electromotive force because he
feared students would take the idea of pressure literally. He felt that the students might reject it since they were unlikely to visualise the kind of pressure the cell exerts (Schwartz, 1993). When the researcher asked this teacher why he chose "potential energy" as the analogue instead of pressure to explain electromotive force, he said:

"My experience is that when I use pressure in water tanks, students are not convinced that the cell exerts pressure. But when I use energy, from their knowledge of chemical energy conversion to electrical energy, they get convinced."

Students understood explanations in a human context. The analogies that were teased out of the students resembled those that their teachers used. For example, when students M, N, P, Q and R in 17W were asked by the researcher what they understood by the terms constant and variable resistors, they explained them using humanised analogies. Student M in 17W said “Peer pressure. Peers usually endeavour to oppose a decision they don’t like OR If you do not stay firm in your decision”. Here, the student was explaining the characteristic of a variable resistor. If one is not firm, then the decision changes, which similarly means that a resistor that does not stay constant varies. In this case the student has understood the available resistor in human terms, which is typical of the African way of viewing things. Mudimbe (1988) indirectly acknowledges this in his notion of “African traditional systems of thought.” He considers these systems as “…dynamic processes in which concrete experiences are integrated into an order of concepts and discourses” (p.ix). What Mudimbe is saying is that African traditional systems of thought are always in a state of transformation depending
on the nature of experiences. This in turn affects the concepts and discourses associated with the experiences. The experiences and the related concepts are integrated.

The analogies used were spontaneously generated, i.e., they were neither planned nor systematic. However, it is possible for some of the analogies to be considered "planned" even if they were not put on paper. For example, the water tank – emf/ pd analogies conveyed the impression that they were planned. This is because the teacher explained emf and pd from the sketch of two water tanks, one with water and the other without (see figure 5a).

This episode displays an effort by the teacher to match the analogue (water system of two tanks) attributes with the target (electric circuit) attributes:

<table>
<thead>
<tr>
<th>Analogue</th>
<th>target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum water height</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>Water pipe</td>
<td>Wire conductor</td>
</tr>
<tr>
<td>Water</td>
<td>Current (implied)</td>
</tr>
<tr>
<td>Pipe opening</td>
<td>Resistor</td>
</tr>
<tr>
<td>Tap</td>
<td>Switch,</td>
</tr>
</tbody>
</table>
The potential energy of water in tank E is at a maximum when the tap is closed. This is compared to the emf of a cell when the circuit is open. When the tap is open, which is an equivalent of closing the switch in an electric circuit (see figure 3b, page 110), the potential energy of the water goes down, since it is dependent on the height of the water in the tank. Potential energy \( P \) is calculated using the formula, \( P = mgh \), where \( m \) is the mass of the water above the level of the pipe connecting the two tanks, \( h \) is the height of the water above the level of the pipe to which the tap (or gate valve) is connected, and \( g \) is the acceleration due to gravity. Similarly, when the switch in a simple electric circuit is closed, the emf of the cell changes to potential difference or emf simply drops. The water flows until the levels are the same (see figure 5b, page 159). Similarly, current will stop flowing between any two points in the electric circuit when the potential difference between any resistor connected in the circuit is zero. However, the absence of discussion about dissimilar features is largely characteristic of unplanned analogies. But in this study, there was only one incident in which mismatches were identified, i.e., in 11W, the recharging of a battery and refilling of a water tank.

Though not so frequently used, there was a case in which multiple analogues were used to explain a single target. In addition, scientific analogues were used as well. Therefore, to explain what electric current is and how it flows, teacher T (14T) said the following:
"When a river is flowing a current develops. Wind flows from a high-pressure zone to a low-pressure zone, that is, from point G to H. What is the difference in G and H? Pressure difference. Something similar to diffusion isn't it? Flowing from a region of high concentration to a region of low concentration. Similar to a river flow from a high altitude to a low altitude. High level and low level result in altitude difference. The difference in altitude causes the river to flow. High potential and low potential give a potential difference, which causes current to flow. The electric current follows the same pattern as the river flow. The terminals are at different potentials”.

It is possible to discern several analogues in this excerpt. Some analogues seem to have been used to explain other analogues. In other words, there were instances of analogical explanations within a cluster of analogues that were used to explain a single target. In this case, the target was, current flows due to potential difference. But as the excerpt shows, the teacher used altitude difference and water flow, diffusion (by referring to a region of high concentration to a region of low concentration), and wind flowing from a high pressure zone to a low pressure zone to explain the fact that current flows because of a potential difference.

Most analogues were environmental, although in some cases cultural practices may have prevented the teachers from using certain elements of analogues considered unconvincing to students. For example, when the teacher was explaining back emf, he used the analogue of a moving car that experiences friction rather than a moving person. For a moving car, it is a convincing fact that when car tyres are worn out, there will be no friction and the car may not stop when the brakes are applied. But the idea of a person walking because of friction is never perceived in mechanical terms. This is probably due to the nature of
African culture that sees events involving humans as controlled by some super power. For example, in the case of a person slipping off the ground, the African does not attribute it to a mere lack of friction; rather, he/she sees lack of friction as caused by some remotely controlled spirits. Jegede (1995) asserts this in his causality notion:

... the cause of a disease which may be quite acceptable to a scientist, may not be so to an African, since misfortunes are normally attributable to the motives of enemies. The scientist may argue that an individual’s fever was caused by the bite of a mosquito infected with plasmodium parasite. The African might still question who sent the mosquito. Or why should it be me? (p.111)

In some cases, the teachers involved students in generating analogies. For example, after teacher W (18W) had explained electromotive force using two water tanks joined by a pipe, he developed the rest of the analogy with the students, an approach advocated by Wong (1993).

Teacher:  “Electromotive force behaves the same way.”
Teacher:  “What is the role of the pipe?”
Student:  “Conductor”
Teacher:  “What other functions does the pipe have?”
Teacher:  “Wide and narrow opening are controlled by the tap. Wide and narrow, which one will deliver more water?”
Student:  “Wider”
Teacher:  “What can we equate to in the electric circuit?”
Student:  “Resistor”
Teacher:  “What about the tap?”
**Student:** “The switch”

**Teacher:** “The lower the resistance the higher the current and vice versa.”

Involvement of students was one of the focuses of an investigation by Wong (1993) which aimed at understanding the generative capacity of analogies as a tool for explanations. He concluded that “self-generated analogies provide the means by which fragments of poorly connected understanding can be accessed and interpreted when explaining scientific phenomena” (p. 1271) and emphasized the importance of involving learners in the generation of analogies by saying, “... productive analogical reasoning can occur when the learners... assume primary responsibility for the task of generating, applying, and learning from analogies” (p. 1271).

This dialogical episode above can be interpreted to mean attribute mapping. Here the teacher may have consciously or unconsciously been doing two things: generating an analogy (Wong, 1993) and mapping the analogue-target attributes (Glynn, 1991; Harrison & Tregust, 1993; Tregust et al., 1992).

Concepts were explained in fragments and no attempt was made to build a whole. For example, emf, pd and resistance (variable and constant) were explained differently but no attempt was made to examine the whole circuitry and explain each component using the applicable analogies. The analogies were “fragment” specific. For example, resistance was explained by use of a different analogue, obstacle in a river; current flow was explained using altitude difference. No attempt was made to bring together these concepts of resistance, current and
potential difference to show how Ohm's law relates them. These concepts and the respective analogues were like a box of tools in which we have specific tools for specific jobs. This is a case of knowledge compartmentalisation and yet the concepts that were being explained are very interdependent. For example, in a complete circuit, variation in potential difference will affect the current flowing in relation to the resistance through which the current is flowing. Ausubel (1963) has argued against compartmentalisation of knowledge by pointing out inherent weaknesses in this way of teaching:

Compartmentalization ... [is] considered a common defense against forgetting. By arbitrarily isolating concepts and information, one prevents interaction with and obliteratorive subsumption by relevant concepts in cognitive structure. This is a modified variety of rote learning in which new learning material is allowed to interact with only one of several potential subsumers. Through over-learning, relatively stable retention can be achieved, but the fabric of knowledge, as a whole is unintegrated and full of internal contradiction. (p.81)

This is probably what Gentner and Gentner (1993) observed in their study of inferential patterns:

The patterns of inference are different depending on which model [is used] . . . People who used the flowing fluid model performed better on batteries than resistors. The reverse is true for the moving crowd people; they performed better with resistors ... p.117)

Implicit in this quotation is the fact that no single analogy can be used to explain a complex system. For example, an electric circuit may require different analogies to explain the various components. In the present study, the teachers and the students used different analogies to explain the various components of an electric circuit. The water analogy was very powerful in explaining electromotive
force, accumulators, potential difference and current flow. In addition, components like variable and constant resistors were explained in anthropomorphic terms. One would have expected the teacher to take care and show how the various elements of the analogue and target are related. But this was hardly ever the case.

Although the tap could have been used to explain variable resistor and current, the teacher chose not to. It was best to compare it with a switch, as the student-teacher's statement on page 161 (boxed) indicates. Instead, students' conceptualisations of constant and variable resistors were revealed in the following researcher-students/teacher dialogue (17W):

**Student N:** [Constant resistor]: “In a river flow, an obstacle like a stone opposes its flow. It will remain the same”.

**Student P:** “Like prefects always oppose wrong doing. Their opposition is the same.”

**Student N:** “In athletics, the other runners [(variable resistors)] always try to stop you from winning. You always encounter varying obstructions.”

**Teacher:** “Athletes always experience resistance from wind that flows in the opposite direction”

**Teacher:** “Consider water in the tank with an outlet pipe at the bottom. The size determines the amount of water let out”.
Nature of Students' Conceptual Frameworks

Some of the analogies either led to the development of misconceptions or confused the students further. Although the teachers seemed to be alert to the possibility of some students forming misconceptions, the researcher still detected some misconceptions during instructional processes and from the student's written responses to the test administered. For example, because a battery was never explained fully, except for the simple statement about a battery and accumulator, many students still confused an accumulator with a battery (i.e., piling up of cells). In response to questions that required students to explain what electromotive force and back emf were, most students treated the two terms as examples of mechanical forces. In other words, despite the detailed and step-by-step comparison of emf and back emf using the water tank and the phenomenon of friction respectively, students still considered the concepts of electromotive force and back emf as examples of force. Typical responses included:

- "Electromotive force is the force present in a circuit from the power supply which causes the motion of electrons from one point to another within the circuit."

- "This is the force required to move electrons from one end which is the positive to the other negative end through the conductor.

The second version contains a misconception: "The movement of electrons from positive to the negative". The same student explained back emf as "amount of force required to move electrons from the positive end to the negative end". This is a case of transfer of errors from one domain to the other (Brown & Clement, 1989).
The following definition of electric current, as produced by some students, is similar to the one given by Abbott (1984). It has implicit misconceptions: "It is produced by two conductors of indefinite length placed one metre apart and if a force of $12 \times 10^{-1}$ N is produced." The students who supplied the response either confused the unit of current, the ampere, with current or memorised the definition of the ampere without understanding. As such, they probably could not remember the definition accurately. More discussion on this issue is provided in chapter six.

Responding to the question of what conventional current is, another group of students said: "This refers to the flow of positive charge". The same group defined potential difference incorrectly. This is likely to have been due to pd's relationship with emf. Emf was defined incorrectly by the majority of the students. The students defined pd as: "The driving force between two terminals in a closed circuit". When defining back emf, most students correctly indicated the opposite direction to emf, but some revealed latent misconceptions too. For example, one student said, "This is the emf that flows in the reverse direction in a simple cell set-up due to hydrogen bubbles that form around the rod".

The misconceptions in this citation include emf flows, back emf is in cells or back emf equals polarisation. Emf flows, indicates how the students conceptualised it. This may imply some equation with mechanical force. Previous studies have indicated that many students view force as substantive (Driver, 1983), that is, forces reside inside bodies they act on and are progressively used up. Back emf being associated with cells stems from the fact that polarisation is a
source of internal resistance in wet cells. Here, the students view back emf as some electrical resistance. It is also possible, although not explicit in the statement that the students may be confusing local action with polarisation in a wet Laclanche' cell. Nevertheless, in the statement, there is some sense of direction, reverse or opposite direction. Although only two misconceptions have been pointed out, the statement appears to be loaded with other implicit misconceptions.

In the process of experiencing the new learning, students’ existing conceptual frameworks were activated as they checked the new ideas against existing ideas. Where conflict was detected, the students voiced their concerns, often in indirect ways. For example, a student suggested that dry Laclanche' cells are rechargeable. Furthermore, the teacher rejected this answer. But later on, when the teacher asked for more examples of rechargeable cells, the same student gave a dry cell as an example. This time the student defended his answer vigorously. He told the teacher that he had experienced this by putting used-up cells in the sunshine and they got recharged. The student assertively said that he had placed completely used up cells in the hot sunshine and later used them. To this student, this was recharging. This leads to the inference below regarding experimental knowledge.

Students put a high value on personally experienced knowledge (Hodson, 1998; Matthews, 1994; Polanyi, 1974) and are even prepared to defend it with vigour. Hodson (1998) sees personalised learning as involving knowledge,
beliefs, values, attitude, aspirations and personal experiences of individual students. Knowledge acquired in this manner is more valued than knowledge which is distant from the learner. That is why, in this study, cases of students defending knowledge they got through experience were recorded. This does not mean that experienced knowledge is always correct. Sometimes, because of misconceptions in the pre-experience knowledge may be used to interpret the experience (transferred to the new knowledge). This is because, prior knowledge plays a role in the meaning making of experiences (Ausubel, 1963; Driver, 1993; Driver & Erickson, 1989; Kelly, 1955). In fact, as Matthews (1994) points out, students sometimes do not change their alternative views, instead they are able to operate between the "knowledges" (Worsely, 1997) switching from one framework to the other as the need arises. In other words, when in class, they give the teacher the response he/she wants and when with the peers, they supply responses according to the principles that the peer groups follow as already seen, sort of what Claxton (1993) calls "stances". Such students construct meanings side by side – Western (scientific) and traditional (culture related) meanings. This kind of knowledge acquisition is what Jegede (1995) calls collateral learning. He defines collateral learning as “… the process whereby a learner in a non-Western classroom constructs, side by side …Western and traditional [(cultural)] meanings of a simple concept” (p. 117). This kind of knowledge according to Jegede is the knowledge that students in a non-western classroom setting will
declare when the need arises or depending on the circumstances – Western or traditional environment.

The following part of student-teacher dialogue was captured during one of the lessons. It reveals students’ strong belief and conviction in experienced knowledge:

**Student V:** “When the cell is finished I usually put it to recharge in the hot sunshine.”

**Teacher:** “I have seen some people do that but it doesn’t last.”

**Student Z:** “But also car batteries. People keep on buying new ones.”

What student Z is suggesting is that if recharged dry cells do not last, then car batteries do not last either, since at one point or another, car batteries are replaced. In other words, the length of time a battery or cell is used is not a valid criterion on which to judge which cells are rechargeable and which are not. People recharge car batteries whenever necessary. This goes on for some time until they can no longer be used. Eventually they dispose of them. Similarly, dry cells are discarded. Therefore, to this student, the *duration period* is again not a factor in deciding which cells are rechargeable and which are not.

Students rationalised and saw knowledge as developing logically from observation. They embraced knowledge that appeared to appeal to sense data. In other words, most of the time observation has more influence on students’ thinking and understanding of concepts than knowledge experienced or learned in other ways, as the following dialogue depicts:
Teacher: “When you have many cells connected together, then you have a battery.”

Teacher: “Secondary cells are also called accumulators. They can be recharged.”
Teacher: “Can you please give me more examples of secondary cells?”

Student 2: “Accumulator.”

Teacher: “Correct. But what is an accumulator?”

Students: [In a chorus] “Many cells.”

The researcher was not sure why the teacher didn’t react to this chorus response. But, that aside, accumulate may mean piling up and “many cells” has to do with accumulation. This has some implicit meaning of a battery. Therefore, a system of accumulating cells must be an accumulator! Hence, students’ response to the question of what an accumulator is, was a resounding “many cells”. In this response there is logic and rationalisation involved. This is a problem caused by everyday usage of the word accumulate and other similar words. Everyday usage in most cases conflicts with the scientific usage. Other examples include words like force, energy, cell, molar and volume.

Wrong ideas that students develop out of experience are not always discarded (Claxton, 1993; Hodson, 1998; Matthews, 1994). The students may retain and display them in new situations. This poses a challenge for the way teachers make decisions regarding the assessment and handling of students’ preconceptions. Whether intentionally or not, the students always look for new situations or explanations that agree with the knowledge they already have (Hewson & Thorley, 1989; Kelly, 1955; Posner et al., 1982) and they seek
knowledge which appeals to common sense. For example, the teacher had previously rejected the idea of recharging a dry Laclanche' cell in the hot sunshine, but later in the lesson, the same student who had suggested this idea revived it in a very indirect way. This time, the student tested the idea of the process of recharging and not the idea of a dry Laclanche' cell as rechargeable.

Teacher: “What should be done to remove the white substance, lead sulphate, formed in a lead acid battery after it has been used for a long time?”

Student V: “Use something that can provide heat to remove the white substance.”

Student V is the one who suggested the idea of recharging a dry Laclanche' cell in the hot sunshine. Now, he has suggested using heat to remove the white substance formed in the lead acid battery. It seems to this student that recharging has to be by heating. In other words, the student accepts the fact that dry Laclanche' cells cannot be recharged. However, the implicit message the student conveys is that dry Laclanche' cells cannot be recharged but the batteries, which are secondary cells, are recharged by heating. One wonders whether this student’s idea of recharging by heating is made more robust by the fact that when a battery is being recharged, it warms up. This reinforces the view that knowledge developed through sense experience is not easy to undo without a good and convincing reason.

Once a misconception is established in one domain, it continues to affect understanding of information in other domains where that knowledge is required.
or is seen to fit. For example, a misconception in the area of electricity was established from the idea of "how current flows". Current flows from positive to negative. This is the direction of conventional current. Now, in mechanics, a vector quantity has magnitude and direction, so logically (at least, for students) current fits this definition. Magnitude which is represented by amperes and direction represented by positive to negative become the bases on which current is classified as a vector quantity. In the following dialogue, a case of error transfer from one domain to another can be argued:

**Teacher:** "What kind of quantity is velocity?"

**Student 2:** "Vector quantity"

**Teacher:** "Yes, give me examples of vector quantities"

**Student 4:** "Voltage"

**Teacher:** [Indirectly rejects this response.]

**Student 6:** "Current."

**Teacher:** "But we said voltage is not a vector quantity and therefore it follows that current is also not a vector quantity."

**Student 6:** "But sir, current flows from positive to negative and electrons move from negative to positive."

Although the class ended and the teacher told the students to read more before the next lesson, the reader can still make sense of the frameworks in which the students in the dialogue were operating. Students had a wrong view of direction, which they used to classify current as a vector quantity. In other words, this is a case of everyday understanding clashing with mathematical
understanding. This will become clearer in chapter six when the meaning of
direction is discussed.

Students not only interpret new information in terms of the knowledge
they already have, they also try to interpret the knowledge they already have in
terms of incoming information. In other words, students assimilate or
accommodate new ideas within their existing frameworks (Ausubel, 1963;
Hewson & Thorley, 1989; Posner et al., 1982). The process of assimilation (see
chapter 2) implies "... infusion of or interaction between related elements rather
than the substitution of new stimulus [(accommodation)] ... in a previously
learned ... [knowledge structure]" (Ausubel, 1963, p.62). Accommodation is said
to take place when there is replacement or reorganisation of existing concepts and
conceptual frameworks. This leads to a new conceptualisation of the situation
(Hewson & Thorley, 1989; Posner et al., 1982). When the incoming idea agrees
with the students' preconceptions, it gets easily assimilated. The problem is when
the incoming and the existing ideas conflict. Several things may happen: the new
idea may be transformed in order to be accepted or it is rejected. And if the
incoming idea is more reasonable, then it gets assimilated into the existing body
of ideas. This will depend on the plausibility, intelligibility and fruitfulness of the
new idea (Hewson & Thorley, 1989; Posner et al., 1982). If the new idea is
convincing and acceptable compared to a competing existing idea, then the latter
gets replaced and a new framework is generated. Sometimes the incoming idea
requires a reorganisation before being accepted. This process is what Piaget calls
accommodation. Assimilation can be problematic, since not all information accepted is "correct", as was observed amongst the students involved in the current study. They interpreted the existing information in terms of incoming information. For example, the students already had the knowledge of current, how it flows and in what units it is measured. When the definition of a vector quantity was provided, the students quickly searched their stock of existing knowledge to determine what fitted the new definition. Current seemed to "fit" the definition. The significant words in the definition of a vector quantity are magnitude (measurability) and direction. These words seem also to "apply" to current and voltage. Current is measured in amperes (magnitude) and flows from positive to negative (direction). Then, why is current not a vector quantity when it apparently has magnitude and direction? This is the kind of question that any teacher has to address step by step, showing what is meant by direction in terms of vectors and direction in current flow (positive to negative).

In mechanics, the idea of force being seen as substantive and contained in a body seemed to be transferred to the conception of electromotive force. The following statements about emf and back emf suggest that emf/back emf moves:

a) "Is the emf which moves from the negative to positive round a complete circuit."

b) "This is the voltage that goes back into the voltage source after going through the circuit."

The latter statement about back emf is likely to be a case of transfer of a misconception from the force domain to the electricity domain. If force is
considered to be inside a body and moves, and also if back emf is a force, according to this student, emf or back emf should also move.

The students took some terms in physics literally. The ideas expressed in (a) and (b) above, provide a testimony to this assertion. Other responses that showed students adopting literal meanings include bemf and pd:

**bemf:** “This is the force supplied in the circuit that helps in case the main supply source fails”

“This is the amount of emf that goes back to the cell”

“...is the force that helps to drive electrons across a circuit”

“This is standby supply of electromotive force which helps current flow in a circuit in case the main supply fails.”

**pd:** “This is the difference between current from a source and current getting to the load...”

“This is the difference between the amount of current flowing in different resistors”

Many students fail to distinguish between potential difference and current. This was evident in students’ explanation of pd:

“This is the difference between current from a source and the current getting to the load...”

“This is the difference in the amount of current flowing in different resistors.”

“This is the difference in the amount of current in the end of the conductor.”

“This is the difference in current in two points in a circuit...”

“This is the difference in amount of electrons between two points in an electric circuit, which results in electron flow so that the two points have equal resistance.”
The students who supplied these responses considered pd and current as identical quantities. These two quantities are part of Ohm's law and it is possible that the confusion arose from their relationships (pd = current \times \text{resistance}).

Not all environmental or familiar analogues convey the message the way it is intended. The water tank analogy appeared convincing and familiar to the students. Even the attribute match between the water tank and emf/pd seemed easily visualisable. However, looking at the students' definitions of emf and pd in the test, one is left wondering what went wrong. The answer may be located in the use of bridging analogies (Brown, 1993; Clement, 1993). The bridging analogy may involve showing that pressure in a water tank indeed varies with depth or height. Otherwise, before this is established, many students have a problem in using a water tank analogy to understand Ohm’s law. This problem relates back to the issue of compartmentalisation of knowledge. When related concepts are explained as packets and no full picture is provided, the outcome is likely to be a “confusion”. Bridging analogies become necessary in such situations. According to Brown (1993), “... bridging analogies are conceptually intermediate [between] situations, in drawing out valid anchoring conceptions …” (p.1273). Such analogies help students in constructing explanatory models that aid learning (Brown, 1993).

Some of the students seemed to lack a deep understanding of polarisation, as the following teacher-student dialogue indicates:
Teacher: “What are some of the changes that occur after a dry cell is completely used up?”

Student: “It becomes softer.”

Teacher: “Why?”

Student G: “The hydrogen gas produced makes it so.”

Teacher: “Are you sure?”

Teacher: “What is the role of manganese dioxide? And why is it close to the carbon rod?”

Here, the teacher was trying to lead the students into seeing the reason why hydrogen was not the likely reason for the softening of the cell. By mentioning manganese dioxide and closeness to the carbon rod, the teacher may have wanted the students to think of the role of manganese dioxide as an oxidising agent. Closeness to the carbon rod was meant to trigger in the students’ minds the place where the oxidised hydrogen is produced. But as the following response by student H shows, one of the students ruled out the idea of water as a possible softening agent because starch was present.

Student H: “Manganese dioxide is a depolariser.”

It is clear that the student probably does not understand the depolarisation process. The response suggests an a lack of understanding of the process of polarisation. Otherwise, if the student knew what depolarisation is, the teacher’s question about manganese dioxide should have “triggered” in him the possibility of formation of water. The teacher even asked a question that suggested the cause
of softening of the cell as the product of depolarisation. But the student still could not see the correct reason for the softening of the dry cell.

**Teacher:** “Could there be water?”

**Students:** [in a chorus] “No! no! no!”

**Student I:** “Sir, this is a dry cell. [Suggesting that there is no way the softening can be caused by water].

**Student I:** “Also there is starch as you told us.” [Starch absorbs any water. In chemistry, students learn that starch is a drying agent].

This means that once starch is included any water formed will be absorbed. The students’ reasoning stops here. But the idea of starch getting saturated does not come to mind. In other words, students’ reasoning was blocked by:

(i) the fact that the cell is dry, and to the student concerned this was enough reason to rule out any contribution to softening by water;

(ii) the fact that there is starch (a drying agent) to absorb any water, limited their perception of what causes the softening of the cell.

What this means is that students’ existing knowledge is a factor in accepting or rejecting new information (Hewson & Thorley, 1989; Posner et al., 1982).

Although, the idea of the zinc container reacting with ammonium chloride jelly to form zinc chloride was never suggested, it could have been an acceptable alternative to the formation of water. In reality, the softness of the cell is a result of two factors:
(i) During depolarisation, manganese dioxide reacts with hydrogen to form water, which is absorbed by the starch. But this starch gets saturated and the cell gets moistened.

(ii) The zinc container (an electrode) reacts with ammonium chloride (an electrolyte), to form zinc chloride (a soluble salt).

These two processes/reactions contribute to the softening of the used dry Lachlanche' cell.

Although several other misconceptions were noted, those listed above are sufficient to illustrate the need for careful use of analogies. Analogies may not necessarily have potential for misconceptions but learners may intuitively be constructing alternative meanings based on misconceptions that already exist in the scientific knowledge they possess.

There was a general practice among the teachers of not explaining the environmental analogies fully. This was probably due to the fact that they were drawn from the students' familiar sociocultural environment. This observation was in contrast to the study reported by Thiele and Treagust (1994), which showed a high frequency of analogue explanation by teachers and attributed it to the lack of analogue familiarity among the participants. They further observed that in some cases analogies worked well for certain aspects of target knowledge. Gentner and Gentner (1993) also replicated this finding. In the case of Gentner and Gentner (1993), both the water flow and moving crowd models worked better
for different resistor arrangements. This idea is implied in 18W during the
dialogue between the teacher and the researcher.

**Researcher:** "Why did you use potential energy instead of pressure in
your water flow analogy?"

**Teacher:** "My experience is that when I use pressure in water tanks,
students are not convinced that the cell exerts pressure. But
when I use energy, from their knowledge of chemical energy
conversion to electrical energy, they get convinced."

**Researcher:** "And why did you use two water tanks as opposed to the
cyclic flow diagram that most people use?" (see figure 3a, page 111).

**Teacher:** "I have found that I can explain everything in an electric
circuit using my diagram. The water circuit diagram is difficult
because it doesn't explain emf well. Again, when we are
solving problems, a pump is considered a resistor and yet, here,
it is providing emf. The students get confused."

Apparently, some of the detected analogies (e.g., 4T, 5T, 15T) were
somewhat *simple* in nature. These, according to Harrison & Treagust (2000), are
analogies in which “... the relationship between the analogue and target is
obvious without explanation" (p.1018). But what is simple to the teacher may not
necessarily be simple the students. Assumptions of this nature may easily
contribute to *silent* formation of "misconceptions" by the students. However,
inferences that have been discussed in this section are some of the key patterns
observed or discerned. It should be pointed out that, like any other case study,
these observations are specific to this case. They only provide an insight into what
may be experienced in form two physics classrooms in Kenya. The question is
whether these analogies were successful or not. This question cannot be
adequately answered by this study. However, it is important that cases that showed signs of success be acknowledged to some extent so that one can learn from them.

The use of these analogies appears to have contributed to the students’ understanding of some concepts in electricity. This was partly revealed in responses to a test which included items on analogously taught concepts (as discussed on page 112). The topics tested included the electromotive force, current, circuit, closed circuit, open circuit, like charges, unlike charges, back emf, conventional current, potential difference, variable resistance, constant resistance and function of a fuse. With the exception of responses to test items on emf, back emf and potential difference, all the other responses were fairly correct. Students displayed misconceptions in their answers. They were mostly definitions rather than explanations. Nevertheless, these were still considered appropriate. Moreover, those cases where students generated their own analogies (16S) may have also influenced their learning” (Pittman, 1999). However, a written test alone can not tell much about the success of the analogies, but one can still learn from it. Other methods such as follow-up interviews with students and monitoring of students’ use of concepts in other contexts can be used to complement testing.

The chapter that follows discusses the findings of the study, interpreting and linking them to theory, existing literature and the context of the study.
Chapter Six

Discussion

From the data analysis (see chapter five: Data and Analysis), two major characteristics of the detected analogies are discerned: environmental (cultural) and anthropomorphic.

Environmental Analogues and Analogies

The analogies used by the teachers in this study were mostly simple (Harrison & Treagust, 2000) environmental (cultural) in nature. This means that the teachers drew analogies from the "assumed" students’ everyday cultural environment and probably influenced their inattention to explanation. However, there was no evidence of any attempt to organise or review the analogue and target structures before comparing them. In other words, the first step of the WWA model (assessing students’ prior knowledge of the analogue) and the second step (assessing students’ prior knowledge of the target) were not addressed. This failure to assess students’ prior knowledge of the analogues and targets assessment did not in any way reduce the importance of environmental analogies. But instead it may have contributed to the reduced effectiveness of the analogies. Despite this, the researcher still recommends the use of environmental analogies. A study by Lagoke et al (1997) provides evidence in favour of the use of environmental analogies. In the Lagoke et al. study, use of environmental analogies resulted in a reduction in the gender gulf which had existed in the
understanding of science concepts - the girls’ performance in science improved significantly, almost matching that of boys.

The use of environmental analogues ensured that the introduction of new and unfamiliar ... concepts began from prior knowledge of the students, which bears specific relation to the daily life of the students’ society. Cultural traditions and beliefs in ... society ... exerted some effect on science teaching ... (Lagoke et al., 1997, p.376)

Environmental analogies play an important role in reducing the gulf between social factors and knowledge construction in science (Lemke, 1990). The common practice in science teaching has been to consider knowledge construction as independent of social factors. But, the noted success of using environmental analogies (Jegede, 1997) (from the socio-cultural environment of the learners) is a strong pointer to the fact that knowledge construction is in part socially influenced. In other words, meaning is negotiated through social and physical interaction (Hodson, 1998). Furthermore, the meaning assigned to new information by any learner largely depends on the knowledge he/she already has (from which analogues are selected). To reinforce the fact that social factors influence what students learn, Krugly-Smolska (1995) says, “... although the exact influence is difficult to pinpoint, there is no doubt that culture affects learning to some degree, whether through cognitive development, cognitive and learning styles, language or worldviews” (p.48).

This point is also reflected in the views of Thiele and Treagust (1994) on analogies. They say that:

The strength of analogies lies in their reported ability to provide additional visualization of abstract concepts, to compare similarities with the
students’ real world, to allow for increased student motivation, and to encourage teacher[s] to consider students’ prior knowledge. (p.228)

The real world of students as used in the above quotation may partly include the socio-cultural world in which the students live. Therefore, the analogues the students understand best include those drawn from their everyday socio-cultural environment. But, analogies have been found not to be as effective in the classroom as expected (France, 2000; Harrison & Treagust, 2000; Lagoke et al., 1997). The ineffectiveness is probably due to the failure on the part of teachers to consider students’ cultural background when designing analogies. In almost all the analogies used in the current study, there were no explicit attempts by the teachers to ascertain students’ knowledge of both the analogues and the corresponding targets, as required by WWA and GMAT models. There were also no explicit cues for the retrieval of analogue knowledge as required by both WWA and TWA models. What was evident was that the majority of the targets were introduced and explained using environmental analogues. In most cases, the analogue-target match was holistic, as opposed to the individual attribute match required by Glynn’s TWA, Zeitoun’s GMAT and Nashon’s WWA models.

However, as discussed on page 159 and illustrated by figure 5a and 5b, the researcher considered the instance as one in which the teachers developed an analogy systematically: matching the attributes as he dialogically involved the students in generating the analogy. In an effort to explain to the students the flow of current using the water-flow analogy, the teacher attempted some attribute matching by referring to the two water tanks connected by a pipe. Water tanks are
a common feature in school premises in Kenya. They are for the storage of water use and in some schools for use during the time when, say, municipal water is not available. However, even though there was attribute matching, it was not wholly based on a systematic model. For example, information about students' prior knowledge of the analogue or target was not sought. Also, no dissimilar attributes were identified. Previous research has shown that this is quite common among users of analogies. They tend to focus on attributes that match. But ignoring mismatches may lead to the development of misconceptions among students. Sometimes presenting mismatches to the class can activate notions that conflict and, in the process, a compromising resolution may be reached; one that brings about conceptual change in the students (Hewson & Thorley, 1989; Posner et al., 1982).

**Anthropomorphism**

Quoting Jegede and Okebukoila (1989), Lagoke et al. (1997) show how in most African classes students *switch off* when they realise that what is learned in science does not relate to their day-to-day life experiences. It is on the basis of this that these African scholars of science education suggest a need to harness all the beneficial aspects of African culture to make science more accessible to African children. Attempts to do this were evident in the classrooms in which the current study was conducted. In the dialogical discussions between the students and the teachers in the study, anthropomorphic statements are predominant. The teachers often used language appropriate to the cultural background of the
children. For example, presenting electrons as animates is typical of African culture (Jegede, 1995). Reiterating the point that culture is an important factor in the understanding and use of science or scientific concepts or knowledge, Lagoke et al. (1997) quote Ogunniyi (1988) as emphasising the fact that,

... human beings tend to resolve puzzles in terms of the meaning available within a sociocultural environment. Since the meanings so formed become firmly implanted in the cognitive structure and manifest themselves habitually, they can then act as templates, anchors, and inhibitors for new learning. (p.368)

In this context, the sociocultural practice is Africans’ belief that everything has life. The idea of in-animates seems not to exist to any significant extent, and where the idea exists, it is in one way or another linked to human control and patronage. “In-animates” can be “animated” by superpowers possessed by some other members of the society. Such powers are exclusively for the few and such knowledge is secret and unwritten. Knowledge of this nature is not written but orally conveyed (Coetzee & Roux, 1998) or acquired after many years of apprenticeship (Mudimbe, 1988). In the researcher’s experience, even where there is a claim that those with such knowledge have revealed it to some other “foreigner”, in most cases, what they reveal is “first aid” knowledge. The inner or deeper knowledge is never revealed to anyone except a member of the family who is perceived and trusted to be the heir to such knowledge. Knowledge of this nature has both restrictions and a strict code of practice. For example, the heir to such knowledge is not allowed to practise until after the incumbent practitioner dies. Although these details are not of direct relevance to the current research,
they serve to emphasise the anthropomorphic nature of African passage or transfer of knowledge. For example, in the current study, in chapter five, 6T, the teacher talks of “visitors" of copper:

“electrons move through the bulb causing it to light. The electrons become visitors of copper. We are going to talk of those friends of copper”.

Here, the teacher portrays an electron as having life, being friendly and paying a visit. Copper is also portrayed as having life, being befriended and visited. The way electrons are perceived may change but their effects may not. Usually we study the effects of electrons. However, abstract terms such as electrons, and the way they are conceptualised, depend on many factors that include cultural factors, social factors, tools of teaching (e.g. analogies) and the knowledge the learner already has.

To repeat, it is common practice among Africans to relate to every creation by assigning it some form of life. Furthermore, as Jegede (1995) has shown, it is important to always consider the environmental setting in which the learner is located.

... [T]he current information available on human problem-solving indicates that the way students represent the information given in a ... science problem, or in ... [the] text they read, depends upon the structure of their existing knowledge. These structures enable them to build a representation or mental model that guides problem solution and further learning. (Jegede, 1995, pp.99-100)

Quoting Ziko (1989), Jegede (1995) further shows that,

It is not the environment of external stimuli that influences our behaviour but rather it is the meaning that each individual attaches to his
or her experiences of the environment and this meaning is influenced by an extremely complex myriad of social and cultural factors... (p.100)

This view is consistent with mild social constructivism, a paradigm that considers social environment as playing an important role just like the natural role the world plays in shaping science knowledge construction (Hodson, 1998, Hodson & Hodson, 1998a, Kragh, 1998; Matthews, 1994; 1998b). For example, Hodson and Hodson (1998b) have argued for a shift in emphasis from the naïve constructivist view of teaching and learning science to what they describe as "... a social constructivist view anchored in the Vygotskian notion of education as enculturation" (p. 17). The process of enculturation as a way of knowledge acquisition is derived from what Hodson and Hodson (1998a) call the notion of appropriation. They argue that:

Knowledge, skills, practices and language constitute a form of 'collective memory' built up over many years. By acquiring elements of this 'collective memory; and learning how and when to use them, individuals are inducted into the cultural resources of society - in effect, being admitted in the community of practitioners and empowered to employ its resources as their own (p.37).

Here, Hodson and Hodson seem to advocate enculturation as the way to plan the teaching of science concepts. In their view, "... individual development is shaped as much by cultural as by biological factors, as much by social factors as by individual effort" (p. 37). This is similar to the view advocated by Jegede (1995) and partly by Bentley and Watts (1994). They convey the idea that knowledge is situated as a product of activity, context and the culture in which it is developed and used. Certain ways of seeing things may cut across cultures.
Both Jegede (Nigerian) and Watts (British) recognise the value of humanising things, which is essentially what anthropomorphism is all about. For instance, according to Jegede (1995), traditional styles of teaching too often ignore the influence of culture on what is learnt at school. Watts and Bentley imply this view when they call for a return to anthropomorphic and animistic ideas as a transition to explaining correct science concepts. And, in the case of Kenya, people talk of the colonial legacy, one that ignores local contexts and worldview. Many of those currently teaching are products of this colonial legacy. Therefore, a deliberative use of animistic and anthropomorphic ideas is one of the approaches that may be adopted as an attempt to attract more young people into science (Jegede, 1995; Bentley & Watts, 1994). It appears that many scientists confuse using animistic and anthropomorphic ideas to teach science with teaching animistic and anthropomorphic ideas. Quoting Piaget (1929), Watts and Bentley (1994) define animism as the tendency for children to ascribe life to inanimate objects and anthropomorphism as the tendency to ascribe not only life, but also human characteristics to in-animates. Although these definitions refer to children’s ways of viewing the world in the Western (scientific) sense, contemporary literature on social constructivism generally shows that students with different cultural background, more likely than not, have different worldviews of nature.

Most of the analogies used by the teachers in the study were environmental and had anthropomorphic characteristics. However, the form in which these analogies were presented is problematic. Science teaching and
learning may be enhanced on condition that such analogies are systematically
developed and presented on the basis of some kind of theoretical model. Such a
model must be one that provides room for the teacher to consider students' prior
knowledge of both the analogue and the target. This is because, as Jegede (1995)
puts it, “concept development in school science is influenced to a great extent by
social factors, especially students’ socially determined preconceptions and
predilections” (p.101). Jegede further points out that “… the resilience shown
by the prior knowledge of a learner in conceptual change is nothing but a direct
manifestation of the eco-cultural norms of the learner’s society” (p.101). In this
study, the case of a student who was not ready to discard the notion of recharging
a dry Laclanche´ cell by heating it in the hot sunshine is an example. Knowledge
constructed through cultural experiences and reinforced by social and everyday
practices may not be easily deconstructed.

In the context of this discussion, the African concept of the world is that it
is full of life, with every creation having its own life. Africans do not see
themselves as separate from the world in which they live but as an integral part of
it. Therefore, according to Jegede (1995), they cultivate humanistic relationships
with everything found in their environment. In addition, Africans relate to all the
entities in the environment with respect and accord the human a central position
in these relationships. This is what characterises the African worldview of nature
as anthropomorphic. However, this may not necessarily be exclusively “African”. 
Humanised relationships are manifest in analogies such as those used to explain the functions of a fuse, polarisation in simple cells and donor/receptor of electrons in nickel-cadmium alkaline cells. The following statements are clear examples of African worldviews that are anthropomorphic:

(i) “Correction of students’ behaviour” is compared to rectification of ac current (2S, chapter five);

(ii) Separating boys and girls in a mixed boarding school by putting fences around their residences is compared to polarisation in a simple cell;

(iii) Prefects’ opposition to wrong doing is used to explain constant resistance in electric circuits; and

(iv) The idea of functions of a Presidential bodyguard (who must protect the President even if it means dying for the President) is compared to the functions of an electric fuse.

Perhaps Africans see everything in anthropocentric terms because the psyche of the African considers every event as having a “human” cause (Jegede, 1995). This concept is quite different from the positivist-empiricist dispositions of Western culture. Things do not just “happen” in traditional African societies; rather, every event is ascribed a cause interpreted in human terms. Because of the belief that in the continuation of life nothing is taken as accident or probability, African rational metaphysical thought is concerned with why a chance or an accident occurred (Jegede, 1995). This is unlike the Western system of thought, which sees accidents
as involving conjunctions for which no law is known and whose elements may be
seen as not necessarily relevant to each other.

It is this background that the African child, and to some extent the African
teacher, takes to science lessons. These sociocultural factors affect school science
learning/teaching and performance (Krugly-Smolska, 1995, 1996). After all,
according to Jegede (1995), science education is a cultural and human enterprise
involving the transmission of the cultural heritage of a people. When this is
applied to the present study, it means that the analogies the teachers used seemed
to make sense to a lot of students. However, the anthropocentric view of the world
should not obscure the scientific (Western) view of science. Science as a culture
has its rules to play by. It also has its language. Although an electron may be
portrayed as talking or having life, the teachers need to point out to the students
that, in reality, the electron does not have a life in human terms. It is not like a
germs or a virus. The anthropomorphic analogies should only be used to help the
learner appreciate the effects that relate to abstract concepts. In other words, an
analogy is a teaching device, not the object of learning.

In multicultural classes, the teachers who receive newly emigrated
children with a different background may consider putting in place a programme
that can help these children ease into strictly science culture, perhaps a form of
controlled "border crossing" (Aikenhead, 1996; Giroux, 1992; Krugly-Smolska,
1995)). Border crossing is a reconceptualised cultural perspective on learning
science. It has to do with the fact that students operate in various subcultures,
which have their own boundaries or borders. For example, a student coming from a non-western culture to join a western culture is faced with the dilemma of choice. Each of the cultures has rules to play by. Yet, the student has to maintain a balance. This balance is not easily attained. Aikenhead (1996), quoting Wilson (1981), acknowledges the enormity of the task of helping students attain this:

It is easy to assert that, to be effective, teaching must take full account of the multi-dimensional cultural world of the learner, but to apply this principle in a particular situation, and to express it in terms of curriculum materials and classroom methods, is a formidable task. (p. 3)

However, the task of teaching involves awareness of the various cultures in a teacher’s classroom. With this awareness, students can be assisted to cross their various cultural borders into the science culture without necessarily losing touch with their mother cultural bases. The crossing does not take place instantly, it requires negotiation of meaning through presentation of information that conflicts with what the learner already believes, in a way that renders the new knowledge plausible, intelligible and fruitful (usable) (Hewson & Thorley, 1989; Posner et al., 1982).

Borders exist in multicultural classes between students’ cultures and the culture of school science. In fact, Krugly-Smolska (1995) rightly says that every classroom is multicultural in composition. According to Aikenhead (1996), students from cultures different from science culture have to cross the borders into the science culture. The size of the border for each student depends on the extent to which the student is already familiar with Western science. A student with a Western science background has a narrower border to cross than someone from a
non-Western science background. For example, children with African background are likely to have a wider border to cross than, say, Canadian or British children. This phenomenon where children have to overcome barriers into the school science culture is, according to Aikenhead (1996) and Krugly-Smolska (1995), "border crossing". The phenomenon of border crossing is similar to what Jegede (1995) refers to as "collateral learning". He identifies at least five predictors of socio-cultural influences on the learning and teaching of science in Nigeria - which applies to Kenya and most other African countries. The factors include:

- Anthropomorphism, which characterises the traditional society that holds strongly the view that the older person is always right;

Good structure, which refers to the interaction pattern among the people of Africa - a pattern that is predominantly co-operative in nature. This is embodied in statements such as "Harambee".

"Harambee" simply means, "pulling together" (Sessional paper number. 10: African socialism and its application to planning in Kenya, 1965; Nashon, 1988). This is a rallying call to Kenyans, first used by the late President Jomo Kenyatta at the dawn of independence, to bring

---

7. "Border Crossing" is a term first used by Henry Giroux (1992). The concept implies "... a recognition of those epistemological, political, cultural, and social margins that structure the language of history, power, and difference". (p. 78). Cultural criticism and pedagogical processes are prefigured as a form of border crossing. In other words, border crossing speaks to the need "... to create pedagogical conditions in which students become border crossers in order to understand otherness in its own terms, and further create borderlands in which cultural resources allow for following of new identities within existing configuration of power" (p. 28).
Kenyans together to build their newly independent country. Harambee is a unity-seeking “Swahili” word. It is derived from the co-operation and togetherness exhibited by tag “pullers

- Traditional world view, which relates to traditional beliefs and superstitions being used as a framework through which experiences are interpreted. In the case of urban centres in Kenya, middle class citizens and their children are fast moving away from this view because of the influence by Western cultures. Some of them have even lived in Western cities long enough to be desensitised to traditional worldviews.

- Sacredness of science, which pertains to conceptual interpretation of science. This has to do with the pervasive view held amongst Africans that scientific views are “incompatible” with the thinking or views of non-Westerners and that science requires magical explanations and is exclusively for Westerners.

- Societal expectations play a pivotal role by recognising the success of an individual in the society as of communal importance. Contemporary African settings have put much weight on science learning since it is a general belief that success in science implies success in life. Perhaps this is due to the frequency with which people with science related qualifications tend to get jobs.
Therefore, those who succeed in science may be the ones who are able to undergo parallel collateral learning. Parallel collateral learning refers to the situation whereby a learner acquires and maintains in the long-term memory opposing schemata about an idea or concept during the learning of science concepts (Jegede, 1995). The student is able to use each of them in ways that are appropriate to the circumstances (switching between the two schemata as he/she needs to). For example, in this study, it seems that the student who persisted with the idea of a dry Laclanche' cell being recharged in the hot sunshine holds two views. On one hand, he may believe that dry Laclanche' cells are rechargeable, and on the other, he may embrace the teacher’s idea that dry Laclanche' cells are not rechargeable. In other words, this kind of student may be using his/her idea in everyday life and in the teacher’s science lessons.

What should not be overlooked is the fact that students come to classrooms with some ideas about some concepts. Furthermore, these preconceptions may be misconceptions or correct conceptions (anchors). Some misconceptions may develop during classroom instruction. However, because misconceptions are actually conceptions based on students’ own experiences, some teachers prefer not to see them as misconceptions. They simply refer to such ideas as preconceptions or alternative frameworks (Driver, 1983; Hills, 1989). The reasoning is based on the students’ experiences with the environment in which they find themselves. Thus, according to Dagher and Cossman (1992) “... teachers’ verbal formulations and their reactions to those of their students, both
oral and written, will determine whether there will be gradual elimination of the
highly undesirable phenomenon ...” (p.362). In other words, context plays a
prominent part in shaping students’ understanding of phenomena: their cultural,
social and scientific background plays a major role in shaping the way they
interpret phenomena.

During this study, some “alternative frameworks” were noted (see chapter
four). The next section discusses the nature of the alternative frameworks
displayed by the students in the research classrooms.

**Nature of Students’ Alternative Frameworks**

This section discusses the characteristics of the alternative frameworks
discerned from students’ responses to test items. As stated earlier, the test was
given after students had been taught concepts in electricity, mechanics and
machines using analogies. Again, as stated in chapter five, mechanics and
machines were excluded from the discussion because of the insufficient number
of analogies used. Consequently, the same topics are excluded from this analysis,
and the discussion is limited to alternative frameworks in electricity.

Because the researcher had no prior knowledge of the analogies to be
used, students’ preconceptions were not determined before the test. Alternative
conceptions were displayed in their responses to test questions on analogously
taught concepts. Therefore, this discussion is about the alternative conceptions the
students held *after* the analogous instructions. Characteristics of these alternative
conceptions, and possible reasons why they constructed them or why the
alternative conceptions persisted (if the student already had them) despite the analogous instructions, will be included in this discussion.

Most alternative conceptions involved back electromotive force (bemf), electromotive force (emf) and potential difference (pd). In chapter five, the alternative conceptions discerned were put into four categories: bemf as
◆ used/standby/returning/helping emf;
◆ current/resistance/moving;
◆ emf and bemf as mechanical force; and
◆ bemf/emf as being inside cells/accumulators.

Two categories of alternative conceptions of pd were discerned:
◆ pd as charge; and
◆ pd as current/resistance/moving.

In general the alternative conceptions (frameworks) exhibited at least one of the following characteristics:

(i) Literal interpretation of technical language.

(ii) Interpretation of preconceptions in terms of incoming concepts.

(iii) Transferring misconceptions from one domain to the other, triggering a chain of related misconceptions in the subsequent domains.

(iv) Misconceptions developed through experience, that persist even in the presence of correct information.
(i) **Literal Interpretation of Technical Language**

Literal interpretation was evident in responses from students that involved the conception of electromotive force (emf), back electromotive force (back emf or bemf) and potential difference (pd). Back emf had the most such statements, including the following:

1. "It is an apparatus used when there is a shortage in the flow of current to help the appliance to continue working". Treating back emf as a piece of apparatus is a misconception, the student nonetheless implies that back emf is “back up” or “standby emf”. This is made even clearer by the fact that this student talks of using back emf when there is a current shortage and that the purpose of bemf is to help the appliance to continue working.

2. “Is the force that helps to drive electrons across a circuit”. It is known that electromotive force drives electrons round circuits. Some students saw back emf as what supports emf. The key word that suggests this view is “helps”: “bemf is the force that helps ...”

3. "This is the voltage that goes back into the voltage source after going through the circuit". Again, although there is a misconception embedded in this misconception - *voltage moving*, the student nonetheless sees back emf as what goes back into the circuit. Back emf is, in other words, seen to be part of the original emf that returns to where it originated. This is literal interpretation.
4. "This is the amount of emf that goes back to the cell". This is the most direct literal interpretation of back emf. This student simply sees bemf as the emf that returns to where it originated.

Teachers are advised to be aware of the fact that some of the misconceptions may never be noticed during instructional processes but may manifest themselves during other occasions, such as when the students respond to test items or examination questions, peer discussions, or any out-of-class student-teacher discussions. The reason is that terminology that appears simple, e.g. back emf, is assigned the literal meaning that is appealing to the students concerned. This may be read from students' "facial expressions", a common method for teachers to diagnose whether there is a conceptual conflict or difficulty in understanding (Thiele & Treagust, 1992). In general, teachers 'know' when the students do not understand and tend to use analogies or other appropriate teaching tools when they consider that the students have not understood the initial explanation. Thiele and Treagust (1992) have pointed out some of the signs that teachers in their study used in deciding whether to use analogical explanation or not:

(a) ... occasionally students would respond to the teachers' questions with incorrect or inappropriate answers. (p.232)

(b) ... teachers ... used analogies in response to blank faces or slightly puzzled gazes. (p.233), or

(c) ... the ability to determine on the spot, when the students were not making sense of the instructions may have been an important clue to the opportunity to provide analogical assistance. (p.233)
This is recognition of teachers’ ability to tell when students need further explanation of concepts. For example, a student’s behaviour or gestures may be used to decide whether to explain things analogically or not. This may also apply to all forms of decision making in any teaching and learning situation.

(ii) Interpreting Preconceptions in Terms of Incoming Information

Usually new information is checked against the knowledge the learner already has (Ausubel. 1963; Driver, 1983; Jegede, 1995; Kelly, 1955). But there were instances in the current study that implied the contrary - cases where students embraced the new concept and supplied responses to questions as a way of concept “fit-testing”.

The case of student L, who wanted to know why dry cells in a radio are wrapped in a polythene paper, is an example of a student trying to “fit-test” a preconception against an incoming concept. It can be assumed that this student was not just interested in a question that had puzzled him for a long time. Rather, he was also trying to test the acceptance of his view that plastics are non-conductors of electricity. Student V might also have been wondering why plastic (polythene) is used and yet it is an insulator or a poor conductor of electricity. Therefore, the teacher’s answer to the question by student L provided student V with an opportunity to test the information he already had. The teacher’s answer appeared to conflict with the idea the two students had. Student V ‘fit-tested’ his idea, as can be discerned from the following dialogue:
Student L: "Before cells are used in a radio, some people wrap them with polythene paper. Why?"

Teacher: "To prevent the solution from leaking onto the terminals."

Student V: "Does it mean that current will flow through polythene paper?"

It is clear that student V had some information about polythene materials and conduction of electricity. Given that the new information came from the teacher, whose word is trusted, student V’s question was a way of testing his idea against the new “trusted” teacher information.

The second case involved the student who for some time had believed that dry Laclanche’ cells get recharged when placed in the hot sunshine. The teacher’s explanation of a secondary cell seemed to confirm the student’s view. This came to the surface when the teacher asked for examples of secondary cells. The student gave a dry Laclanche’ cell as an example. Another student reiterated this example. But the first student was prepared to prove that his response fitted the definition of a rechargeable cell. This intention manifested itself in the following dialogue:

Teacher: "Now, who can give us examples of secondary cells?"

Student V: "Dry cell".

Student H: "Not really. Lead acid cell".

Teacher: "That’s correct."

Student V: "Sir, I am right".

Teacher: "How?"
Student V: "When the cell is finished, I usually put it to recharge in the hot sunshine."

Teacher: "I have seen some people do that, but it doesn't last."

Student Z: "But also car batteries. People keep on buying new ones."

Not only is the student checking his already constructed idea about rechargeable cells using a dry cell as an example, but he is ready to prove his stance by insisting that he has practically recharged a dry cell in the hot sunshine. Notice also how his peer indirectly comes to his defence when the teacher’s dismissive answer appears not to make sense. Student Z does not see sense in the fact that "the dry cells placed in the hot sunshine" do not last long since even the rechargeable lead-acid cells used in cars are replaced regularly.

Therefore, teachers should be aware that students have already constructed ideas which determine the acceptance or rejection of new ideas (Ausbubel, 1963; Hewson & Thorley, 1989; Kelly, 1955; Posner et al., 1982). However, there are also cases, as shown above where students checked their existing ideas, views and beliefs against ‘acceptable’ incoming information. Students make such views known through verbal or written narratives. Teachers are therefore advised to be more systematic in exposing and examining the views students already hold, and then carefully and systematically comparing them with the incoming ideas. In other words, they may overtly use the strategies advocated by the conceptual change theorists (Hewson & Thorley, 1989; Posner et al., 1982).
(iii) **Students' Transfer of Understandings from one Domain to another**

Studies have shown that misconceptions in one domain can affect the understanding of related concepts in the subsequent domains (Duit, 1991). In other words, a misconception in the analogue domain can easily affect students' understanding of target concepts, as Duit (1991) argues: "If students hold misconceptions in the analog[ue] domain, analogical reasoning will transfer them into the target domain" (p.666). Furthermore, Harrison and Treagust (2000) caution that teachers' intentions to use analogies may be rendered unworthy unless they actively negotiate with the students the familiarity of the analogies.

There were instances in this study where students based their reasoning in a given situation on the wrong ideas that they held. For example, one of the teachers asked the students to say what kind of quantity velocity is:

**Teacher:** "(...) what kind of quantity is velocity?"

**Student 2:** "Vector quantity."

**Teacher:** "Yes, give me some examples of vector quantities."

**Student 3:** "Magnetic field."

**Student 4:** "Voltage"

**Student 6:** "Current."

**Teacher:** "But we said voltage is not a vector quantity and therefore it follows that current is also not a vector”.

**Student 6:** "But sir, current flows from positive to negative and electrons move from negative to positive."
For the purpose of the argument in this section, explaining one concept may help the students in understanding a related concept. It is clear from the dialogue that "voltage" as a vector quantity was rejected and, therefore, the teacher may have assumed that it was obvious that the students had inferred the kind of quantity current is. Student 6 insists on the idea of current having direction, positive to negative. Thus, he argues that the current, too, has magnitude and direction and therefore current is a vector quantity.

To repeat, students viewed current as being a vector quantity because they perceived it to have both direction and magnitude. The students argued that current is *measured in amperes* - a measure or an indication of *magnitude* of current - and it flows from *positive to negative*, an indication of direction. Here, one is most likely to infer that the students transferred a misconception from the *mechanics* domain to the *electricity* domain. The misconception was most probably located in the idea of *direction*. When most teachers discuss the flow of current - conventional and electron - they emphasise the "direction" of flow. For example, it is common to read in books as well as to find teachers saying: "The direction of current flow is positive to negative". Similarly, they talk of "direction" of electron flow. Furthermore, to indicate the direction of flow of current in a conductor, one must use an arrow, e.g. →. This is also the way direction is indicated. The important idea is the use of an arrow. It is here that the misconception could have originated.
One obliged to understand the holistic meaning of a vector in order to clarify quantities as vectors or scalars. Vectors have to do with a straight line. Along this line is the indication of direction. Forces act in straight lines. So do all other vector quantities. Current does not necessarily have to move in a straight line from a positive terminal to a negative terminal. The conductor could be curved, zigzag or crooked. Current could still flow. If current was a vector quantity, it would never get to the negative terminal through a crooked conductor. It would be reflected or would change direction at the first bend. So, direction in a vector is tied to the concept of straightness. Therefore, although current has magnitude, the path followed to reach a given destination does not necessarily have to be a straight line. This misconception was initially in the understanding of direction. Straightness was not part of the student’s understanding of a vector. Therefore, the students transferred this misunderstanding of direction in a vector domain to the current flow domain.

It is imperative that physics teachers make it clear to students that a direction in a vector refers to a straight course or a line of action. Beer and Johnson (1988), in their fifth edition textbook, Vector Mechanics for Engineers: Statics, have defined the direction of a force as "... the line of action and the sense of the force" (p. 15). They have gone further and defined line of action as "... the infinite straight line along which the force acts" (p. 15). This applies to direction in all other vectors. The direction of a vector can therefore be considered to mean the line of action and the sense of a vector. By implication, therefore, a
line of action is a straight line along which the vector quantity acts. Current does not have to act along a straight line as we have already discussed. Hence, current is a scalar but not a vector quantity.

Although I have tried to speculate on the possible source of the misconception the students had about the type of quantity current is, the best way one may understand the source of any misconceptions is by interacting with the students — asking them questions, probing their responses and giving them time to reveal their reasons by providing an environment of trust. Students may be advised not view probe interviewing as a way of looking for “correct” and “incorrect” answers. Non-intimidating conditions should prevail as much as possible. This way, the teachers are likely to understand and address the real sources of misconceptions. Well thought-out probe questioning can help teachers to intercept misconceptions that are “enroute” to target concepts via analogies. Because concepts have their meanings located in a network of ideas, and are not isolated “items”, misconceptions that are not checked and intercepted early, can have very serious effects. They can initiate “knock-on” effects just like interconnected molecules. Knocking on one end of a solid, causes each molecule to vibrate, passing over the effect to the next ‘neighbouring’ molecule. This leads to a chain reaction-like effect.

One of the teachers in the study seemed to be aware of this. During an informal interview with the teacher regarding the water analogy, he suggested the potential for students' confusion as a reason that made him decide not to use
pressure difference to explain potential difference. Instead, the teacher used potential energy. The following researcher-teacher dialogue implicitly shows the teacher's concern to avoid transfer of a misunderstanding from one domain to another:

**Researcher:** "Why did you use potential energy instead of pressure in your water flow analogy?"

**Teacher:** "My experience is that when I use pressure in water tanks, students are not convinced that the cell exerts pressure. But when I use energy, from their knowledge of chemical energy conversion to electrical energy, they get convinced."

From the teacher's experience, it seems that students take the idea of pressure in a cell literally. They may not understand what the analogy is all about; instead the teacher uses analogues that he is sure will reduce the number of misconceptions. Although this did not come from the students, the teacher seemed to suggest that the students would transfer the literal meaning of pressure to the cell. And because they do not associate terminals of a cell with pressure (force per unit area) they may not get convinced.

The third and final incident in the study where understanding in one domain is transferred to another domain occurred when one of the students responded to the teacher's question of what should be done to reverse the formation of white lead sulphate on the electrode.

**Teacher:** "What should be done to remove the white lead sulphate?"

**Student V:** "Something that can provide heat to remove the white lead sulphate."
Earlier in the lesson, student V had argued that dry cells are rechargeable when placed in the hot sunshine. According to the teacher's response, the focus was on the cell, whether it is rechargeable or not. The action of hot sunshine was not mentioned. It seems this conveyed to student V the idea that only the cell is non-rechargeable but the process of recharging was acceptable. Of course, this was a misconception. Later, this idea manifested itself in what should be done to the lead-acid battery to reverse the formation of lead sulphate. The student suggested using heat to reverse the formation of lead sulphate. Of course, this is not correct. It is possible that a previous observation that batteries warm up when they are being recharged may have reinforced the student's view that heat is a factor. But there is a high possibility that idea of heating was transferred from the dry cell domain to the lead–acid battery domain.

These cases are not conclusive but are a pointer to what goes on in the complex process of teaching and learning science. Teachers have to be alert for any cases of misconceptions that are beneath a surface answer, like the one of recharging dry cells in hot sunshine. "Using hot sunshine" as a process of recharging cells was not examined by the teacher at the time it was first suggested. It was only addressed when it resurfaced as the teacher was discussing a new concept. In other words, students' statements may contain a multiplicity of misconceptions. It is possible for some of the misconceptions to escape notice, only to affect subsequent conceptions, especially if teachers are not alert.
(iv) *Misconception Developed through Experiences can persist even in the Presence of Correct Information*

Lived experience may be a good way of learning. But there are activities that can convey wrong ideas to the students - ideas that subsequently persist in the midst of correct explanations. An example in the present study was the case of recharging a dry Laclanche' cell, already cited in (ii) and (iii) above. Despite the attempt to explain the construction and use of a dry cell, one of the students persisted with his view that a dry Laclanche' cell is rechargeable. This student used his experience of placing the cells in the hot sunshine and continued to refer to this experience in defence of his view. This was further complicated when the teacher acknowledged having seen some people doing that, and that such recharged cells had a short life span. Another student who saw sense in his colleague's response indirectly challenged the teacher's reason. In other words, the fact that the teacher had seen some people put cells in hot sunshine, and them not lasting, was not a convincing reason to suggest that dry cells are not rechargeable.

**Student V:** "When the cell is finished, I usually put it to recharge in the hot sunshine."

**Teacher:** "I have seen some people do that but it doesn't last."

**Student Z:** "But also a car battery. People keep on buying new ones."

Student V is reiterating what he has experienced. How can it be different from what he has seen? Student Z appears to show the teacher that it is not how long the cell lasts that determines whether it is primary or secondary. If it was so, then
car batteries which are rechargeable and at some stage are disposed, would not be considered rechargeable. Teachers should therefore be sensitive to and be aware of how robust such ideas can be. If such ideas escape notice, they will manifest in one domain or the other. But the fact that they are constructed out of experience makes them hard to deconstruct. Any attempt to deconstruct them should be accompanied by activities that can provide a counter experience based on the principle of plausibility, intelligibility and fruitfulness (Hewson & Thorley, 1989; Posner et al., 1982).

**Advantages of Analogy Use**

According to Duit (1991), analogies are valuable tools in bringing about conceptual change during learning processes that open new perspectives. They facilitate understanding of the abstract by pointing to similarities in the real world. In addition, analogies provide visualisation of the abstract as well as provoke students’ interest. The fact that analogical problems can be solved by both academically more able and less able is an indication of how useful and powerful analogies are (Wilner, 1964). After all, teaching aims at enabling every learner to access scientific knowledge.

Analogy’s role in enhancing students’ learning cannot be over-emphasised. It is part of every teacher’s repertoire and even part of everyday speech. Thus, Brown and Clement (1987) say:

The use of analogy is often viewed as one of the primary means of drawing on students’ existing knowledge. By activating prior
knowledge, which is already understood by the learner, the analogy helps give meaning to incoming information (p. 237).

How successful the analogies in the study were in enhancing students’ understanding of the associated concepts is not easy to tell. France (2000) reinforces this view by noting that, “Analogy are powerful communication . . . devices provided their use is carefully orchestrated . . . Effective analogies . . . must be familiar and accessible to students . . .” (p.1163). The short informal interviews with the students and the single test that was administered can not be used as conclusive evidence for the success of these analogies. However, any conclusion from the episodes serves as a pointer to what may lie beneath what was observed.

Some episodes present an encouraging picture about environmental analogies. For example, 18W, which involves an interview the researcher had with the students about resistors, suggests that the teacher’s explanation was well received by the students. These students, in turn, used their own analogies to explain what constant and variable resistors are.

**Researcher:** “Tell me how variable and constant resistors work”

**Student M:** “Peer pressure. Peers usually endeavour to oppose a decision they don’t like. If you do not stay firm in your decision.”

**Student N:** “In a river water flow, an obstacle like a stone would oppose its flow. In athletics, other runners always try to stop you from running to win.”

**Student P:** “Like prefects always oppose wrong doing, no matter what. Their opposition is the same. Like charges opposing each other.”
Student Q:  “Accidents on the road would interfere with the smooth running of vehicles. Running of water on a potholed road.”

Comparing these varied students’ responses to the teacher’s version, one may conclude that the environmental analogies had some positive effect on students’ understanding of the science concepts.

Teacher Version:  “Athletes always experience resistance from wind that blows in the opposite direction.” Or “Consider water in the tank with an outlet pipe at the bottom. The size [of the pipe] determines the amount of water let out” (see figure 1, page 104).

On this same note, most students responded “correctly” to test items involving constant and variable resistors. On the whole, students’ responses were “correct”, except in three areas: emf, bemf, and pd. The other concepts - such as current, constant resistor, variable resistor, conventional current, electric circuit, closed circuit, open circuit, behaviour of like charges, behaviour of unlike charges and a fuse - were correctly explained by the majority of the students (in accordance with the marking scheme). Furthermore, responses that contained minor mistakes were considered correct (because they could easily be fixed) by this study. Such results are encouraging. In addition, the fact that the school in which the research was conducted has an outstanding record of doing well in physics examinations at the national level points partly to the success of environmental analogies, and any other teaching methods the teachers use - methods that appreciate students’ diverse cultural backgrounds (Krugly-Smolska, 1995).
However, there are cases that provide disturbing results. It has already been stated that this ineffectiveness in analogy use is probably due to factors other than the nature of analogies. Such factors may include lack of systematic design and presentation of the analogies used and problems with the medium of instruction, English, which is a second language.

**Disadvantages and Limitations of Analogy Use**

According to Zeitoun (1984), analogies have little effect in the following circumstances:

(i) The analogue used is unfamiliar.

(ii) The students possess enough background knowledge about the target.

(iii) The students lack some abilities such as analogical reasoning, visual imagery and cognitive complexity.

(iv) The number of analogous attributes of the analogy is limited while the number of irrelevant attributes is large.

With respect to item (i), there were cases where one gets the feeling that the analogue used was not well understood by the students. It was clear from test responses that students had difficulties explaining what emf is. One common misconception kept on recurring: that of viewing emf as a mechanical force. This is probably because the teacher used the idea of potential energy of water in a tank. Although the teacher attempted to teach the analogue as suggested by Zeitoun (1984), the idea of potential energy as applied to water in a tank was beyond the understanding of the students. Probably the idea of pressure and height of water in a
tank would have been a better choice for the analogue than potential energy. When the researcher asked the teacher about this he said that he feared the students were not going to accept the idea of a cell having pressure for emf. In other words, pressure (analogue) for emf (target) may not have been a good match because of the way students were going to perceive it.

With respect to (ii), (iii) and (iv), it should be re-stated that the teachers did not present the analogies systematically and did not base the design of analogies on any theoretical model. However, not much can be said about (iii) — analogical reasoning, visual imagery and cognitive complexity - because the tools and the nature of research did not allow the researcher to assess them. This is one area that may require further research or study.

Analogies have little learning effect if the students take the analogies literally. Some misconceptions in the learning of the topic (target) or analogue might result instead. This might be the case with students’ definitions of back electromotive force (bemf). It was one area where many misconceptions were detected. The misconceptions were characterised by literal interpretation. The majority of the responses portrayed bemf as emf that returns, standby emf, emf that provides assistance or emf that helps. So, once the students take analogies literally, the targets will probably be “misconceived”.

Analogies cannot be constructed in situations beyond the limit of our pictorial imagination (Webb, 1985). This appeared not to be an issue with the
analogies that were captured in this study. The reason could be that most of them were environmental and therefore within the grasp of most students.

Analogies are never based on an exact fit between analogue and target. In other words, there are attributes of both analogue and target that do not match and may mislead the students. Nearly all the analogues and their corresponding targets had no exact fit. For example, a water tank (see figure 1, page 104) and the accumulator. While several attributes of both the water tank and accumulator matched, there are features in both the water tank and the accumulator that do not match. In the water tank analogue, the water matches charge in the accumulator, the inlet and outlet taps match the positive and negative electrodes in the accumulator, and the refilling process of a water tank and recharging of accumulator [addition of charge] also match. However, in refilling the tank, one uses the same inlet tap and in recharging the accumulator, one has to reverse the terminals. The acid in the accumulator has no match for the water tank (target).

The majority of the analogies either were holistically applied or were mono-attributal. In other words, because of the tendency to compartmentalise things, every attribute in most targets was explained by a single attribute analogue. For example, a constant resistor and an obstacle in a river flow; a variable resistor and opposition experienced by an athlete. Furthermore, analogical reasoning is only possible if the intended analogies are those drawn by the students (Duit, 1991). If, say, the students hold misconceptions about the analogue, the analogical reasoning will transfer them into the target domain (Duit, 1991).
Analogical reasoning in learning situations requires considerable guidance. However, with careful choice of analogues and careful matching of analogue-target attributes, analogies should be some of the best teaching/learning tools in subjects or topics with high levels of abstraction. In addition, when a holistic understanding is required then multiple analogies may be used (Duit, 1991):

Analogies usually aid learning in specific areas of the target domain. Hence multiple analogies are necessary in order to facilitate learning of the whole [target] domain. (p. 667)

This is a pointer to the use of other analogues for the unmatched target attributes, which, in turn, may constitute other analogies. A case in this study where an indirect use of multiple analogies was captured is 14T. Here, the teacher used “altitude difference as the cause of river flow” to explain “potential difference as the cause of current flow”. This was also explained by the students, using “pressure difference as the cause of wind flow”. Still, the teacher again used another analogue, “diffusion” which is the movement of gaseous molecules between to regions due a difference in concentration, was used to explain the same target (potential difference as the cause of current flow). These are multiple analogues explaining a single target, leading to multiple analogies.

The following chapter discusses the implications of the findings of the study for physics teaching and further research in Kenya and elsewhere.
Chapter Seven

Suggestions for Teaching and Further Research

Teaching Suggestions

Teaching by analogies may be more successful when students know where the analogy breaks down before drawing conclusions about the target. For example, in explaining electromotive force (see 18W- water tank analogy), the teacher did not draw the corresponding electric circuit diagram (target) that was explained by the use of the water tank diagram (analogue) (figure 1, page 105). This could have been due to the fact that most of the analogies were holistically applied or used.

Although there were some cases in the current study where the diagrams were clear and easy to understand, not a lot could be achieved in the absence of explicit mention of dissimilar attributes. In this study, dissimilar attributes and analogical limitations were never mentioned, except indirectly in 12S, the water tank refill and battery recharge analogy. In general, a statement of analogical limitations occurs as a likely consequence of systematic planning of analogies to be used. Spontaneously generated analogies are less likely to consider attribute match than planned analogies. Even when teachers intuitively consider analogical limitations, they may not exhaustively describe all the limitations or dissimilar attributes. The solution may lie in the systematicity principle (Gentner, 1983) and use of theoretical models such as TWA, GMAT or WWA. This study reinforces
the conclusion that construction of an analogy should be based on a kind of theoretical model with a structure that provides systematicity. Basing analogies on a particular model, such as Glynn's (1991) TWA, Zeitoun's (1984) GMAT or Nashon's (2000) WWA is likely to lead to a reduction in students' alternative conceptions or misconceptions. In addition, use of analogies, as one of the important tools of instruction, should be part of preservice and inservice teacher education. This is because of the important role analogies play in concept teaching and learning (Willner, 1964).

Systematic use of analogies has several advantages. For example, assessing students’ prior knowledge of both analogues and targets can be one way of identifying students’ preconceptions that are anchoring and non-anchoring (misconceptions) (Clement, 1993). Analogies that are developed using analogues from among students’ anchoring conceptions can ensure correct transfer of “correct” knowledge. Lack of systematic analogies may mean that in some cases misconceptions in the analogue domain are transferred to the target domain.

Alternatively, analogies can be used in formative assessment. According to Pittman (1999), students can be asked to generate analogies to explain taught information, thus revealing their deep understanding of the concept. If they hold misconceptions, these will be revealed in the analogies they generate. Therefore, according to Pittman (1999), “Student generated analogies could be a tool to assist the science educator in identifying or addressing existing students’ conceptions that are not compatible with scientific conceptions” (p. 19).
This calls on teachers to deliberately plan to have students generate their own analogies to explain already taught material. Of course, this can only be successful if the students are taught how to construct analogies. Thus, it makes sense for student-generated analogies to be preceded by teacher-generated analogies. According to Pittman (1999)

Allowing the student to construct analogical relations from their perspective would allow for a deeper understanding of the base and target. These analogical relations, however, are between the target and the student's self-generated base. Students will then construct similarity relations based on their observations of the base and the target (p.2).

Although environmental analogues were used by the teacher in this study to enhance understanding, there were no attempts to provide comprehensive definitions of terms such as electromotive force, current, and potential difference in students' everyday language. The language of the classroom should be simpler than the terminology commonly found in textbooks. Kilbourn (in press) argues in similar vein when he says,

The usefulness of an analogy comes from its simplicity ... [and] ... lies in carefully painting the detailed parallels between it and a phenomenon to show texture and highlight subtleties - learning comes from methodically painted comparison. (p.3)

Failure to observe what Kilbourn seems to spell out may lead to confusion and misunderstanding. Because of this, students are forced to fall back on the habit of memorising textbook definitions and other "official explanations". In any case, as Kilbourn further notes, "The pedagogical power of an analogy comes from its familiarity and its degree of correspondence to the phenomenon to be understood"
Not surprisingly, Kilbourn has pointed out what many teachers might have observed during their teaching: that analogies are often better understood than the phenomena (targets) they illuminate. And, when students are asked to explain the target after analogical instruction, the majority tend to reproduce textbook definitions or explanation. They do this for the probable reason that during analogical teaching there is a failure on the part of teachers to summarise the meaning of the targets in simple, clear language and perhaps in the language that resonates with the students. For example, responding to the question: "What is current?" one of the students said current “… is produced by two conductors of indefinite length placed one metre apart and if a force of 12X10^{-1} is produced it is said a current of one ampere is produced.”

A popular physics textbook in Kenya is “Ordinary Level Physics” by A. F. Abbott. Instead of starting with the definition of current, followed by the unit of current, Abbott starts with the definition of a unit of current. He defines the unit of current, the ampere as “…the current which if flowing in two straight parallel wires of infinite length, placed a metre apart in a vacuum, will produce on each of the wires a force of 2X10^{-7} Newton per meter length” (Abbott, 1984, p.404). In the Kenya Institute of Education (KIE) physics textbook, “Secondary Physics: Form 1 Pupils’ Book” (1999), current is defined from Coulomb’s law as the “… rate of flow of charge through a given point in an electric conductor” (p.252).

Comparing the student’s definition of current and Abbott’s definition of an ampere, one cannot fail to notice some similarity. Ignoring the inaccuracies in the
student’s definition, it is reasonable to conclude that he was trying to reproduce the
definition of an ampere from Abbott. He seems to consider an ampere and current
to mean the same thing. This may be interpreted as a failure on the part of the
student to see a link between the teacher’s definition, the KIE definition, and
Abbott’s definition of current. Given the history of the Abbott text on the market
for 40 years, the student may have thought that both the teacher and the KIE book
were wrong. Although there is no concrete evidence from the study, the
researcher’s experience leads him to surmise that some students find pride in
reproducing textbook definitions accurately. If the test given by the researcher
were to be graded, this student would have raised queries as to why the teacher had
failed him, especially if he had managed to reproduce the definition of the ampere
correctly.

Students in Kenya are most probably inclined towards memory/rote
learning because of the pressure of national examinations. One may even go so far
as to call it a syndrome. There is intense competition for university or college
admission in Kenya and science subjects have become a requirement for entry into
those institutions. As a result, students would like to see teachers relating whatever
science information they teach to what is given in the “traditional” textbooks. Even
when analogies are used, as in this case, the final summary should show a link
between the message conveyed by the analogy and what students read in standard
textbooks, such as Abbott. Though the incident is isolated, it is important to learn
from it. The nature of examination questions, which is not the subject of this study
and discussion, may be a major contributor to this kind of attitude held by students (Nashon, 1989). Abbott (1984) mentions “current” without defining it, followed by the definition of the unit of current, the “ampere”. To the student, the definition refers to current. One way to minimise this kind of learning, in which students hold various compartments of knowledge about the same topic, is to use environmental analogies. Examples of the compartments include teachers’ knowledge, ordinary textbook knowledge, trusted textbook knowledge and common-sense, everyday knowledge. Not only are teachers advised to use environmental analogies be used but they are also advised to plan their (analogies’) use systematically (Gentner, 1983; Gentner & Gentner, 1983; Kilbourn, in press). The concepts can make sense if they are summarised in very simple, clear language and related to those explanations or definitions in standard textbooks. Hopefully, students will then see the connection between the teacher’s explanation and the textbook explanation.

Given that the students in the study use English as a second language, they are likely to experience difficulties in understanding the textbook language because it is technical. Students turn to memorisation as a final result probably because of insufficient richness in the vocabulary. Whenever possible, teachers may use both locally authored books and foreign authored books like Abbott. Hopefully, locally authored books will have analogues related to students’ cultural environment. There has been an attempt to do that in KIE texts (KIE, 1999). When the definitions and explanations are not identical, teachers can state explicitly their
similarities and, consequently, the students will most probably get encouraged to value understanding as opposed to rote learning.

Although teachers may not have access to all the physics textbooks that the students are exposed to outside the school, it may be important that they use all the textbooks available in the school resources or be familiar with the content of physics textbooks that are commonly available to students within the school. They can also introduce the idea of "a physics box". This is a system that one of the physics teachers in the upper classes was using: students write down problems, issues and solutions to physics related subject matter and place them in the box. At the end of the week the teacher opens the box and goes over the problems, issues and questions collected. He then plans for lessons to include discussion of some of the issues, with issues that touch on topics not yet covered in class being deferred to the appropriate time. However, students who raised such issues were also addressed individually during private study time. The teacher avoided playing the role of "know it all teacher". Instead, he redirected some of the questions to the group or class. In some cases, the teacher arranged for practical demonstrations as a way of providing experiences and opportunity to cause cognitive conflict (see chapter two) - discussion of disequilibration (Dale, 1975; Brna, 1991) that made it easier to reach a rational compromise.

Most students responded correctly or near correctly to the test items on the researcher-administered test. In other words, environmental analogues seemed to work well for a majority of the students but not so well for a small percentage.
When misconceptions are not identified and corrected early, there is little likelihood of satisfactory progress.

Teachers should also recognise that explanatory models can be constructed from anchoring examples, examples that are drawn from the students' cultural environment. These provide visualisable mechanisms to explain the behaviour of targets (Clement, 1993). It is equally important to provide summarised syntheses of the information about the targets in a simpler language that the students can easily understand. The simplified language can be related to the complex textbook information in the form of definitions and explanations. For example, after a teacher has compared the attributes of a water circuit system (figure 3a, page 110) and the electric circuit diagram (figure 3b, page 110), he/she should then make a clear and simple conclusion about the target. A general statement about the target that brings all the points together should be provided. In this case, the pipe, the water, the gate valve and the water pump (figure 3a) correspond to the wire conductor, the current, the switch and the battery (figure 3b), respectively. After a discussion of each match, mismatch and individual conclusions, the teacher should summarise the understanding of the electric circuit by saying something like:

"When the switch is closed the current flows round the circuit passing through the resistor (R). This current (I) flows because of a potential difference (V) that exists between the ends of the resistor (R). The current (I) depends on the number of cells. Varying the resistance (R) can alter it. This relationship is called Ohm's law, expressed mathematically as, \( IR = V \).

The last three sentences are very important; they are a summarised synthesis of the information about the electric circuit. Ohm's law is therefore a
summary. It is instructive to compare this summary with the following Abbott (1984) textbook statement of Ohm’s law:

The current passing through a wire at a constant temperature is proportional to the potential difference between its ends. (p.407)

To understand further about environmental analogies and concept development, more research is needed into the interaction of environmental analogies with student preconceptions. In other multicultural societies, where children of African origin or other immigrant communities are new in science classrooms, teachers should consciously search the students’ new environments and identify whatever they are comfortable with in order to generate analogues that can be used in analogical explanations. Such analogues may be taught to such students (Zeitoun, 1984) before using them to explain new concepts. In any case, according to Krugly-Smolska (1996), “Cultures have boundaries and shared cultural knowledge implies membership” (p.25). In the context of this discussion, it means that teachers necessarily need to recognise such boundaries among the various cultures present in their classrooms and design instructional activities/strategies that would help students from non scientific (Western) cultures cross such boundaries/borders in order to become members of the community of scientists – a phenomenon referred to as cultural “border crossing” (Giroux, 1992, AIkenhead, 1996). By probing and understanding new immigrant children’s knowledge of their new environment, suitable analogies that can help them understand physics concepts. However, such analogies are effective only if the students are fully involved in their generation. This is due to the fact that the
analogues they know best and are comfortable with can really make the new information meaningful and usable (Pittman, 1999). But, if teachers are also not familiar with the analogues (drawn from the students’ new environment) — without feeling a sense of ownership, they will not display or use the analogue to the good advantage of such students. For this reason, teachers and the students should work together to generate analogies that both find meaningful.

**Recommendation for Further Research**

A study like this generates many questions and raises many issues. Some questions may find answers within the study, others may require further research. For example, the question of alternative meanings that environmental analogies may convey to students during instruction is an issue that needs further study. Although this study has touched on this subject, further studies are required to explore the area more extensively. It would be interesting to identify students’ ideas before and after analogous instruction of a particular topic. This is one way to assess the effect of an analogy such as 18W on students’ preconceptions. In the dialogue presented earlier, the researcher assessed students’ understanding of fixed and variable resistors after an analogous teaching. However, because it was not possible for the researcher to tell in advance which concepts were going to be taught analogously, students’ prior knowledge of resistors was not determined. With predetermined analogous concepts, a better method would be to find out what the students know about these concepts before and after the analogous
teaching. This is one way to tell whether or not there was a shift in conceptual understanding. Therefore, more studies are required to establish the effect of analogies on students’ conceptual understanding of target concepts.

In addition, the issue of readiness for analogical thinking is one that requires further study.

This study, being a case study, cannot be conclusive on the nature of analogies used by Kenyan high school physics teachers. It was conducted in a peri-urban area; a study extending to rural and other urban areas in Kenya may be necessary to generate a more complete picture of the kinds of analogies Kenyan teachers use.

Inquiring into any differences in the nature of analogies that male teachers and female teachers use is also necessary. In addition, male and female student-generated analogies require in-depth study and comparison. On this same note, the following studies would be of value: (i) analogies used by male teachers in girls’ schools; (ii) analogies generated in only girls schools and only boys schools; and (iii) analogies generated by girls and boys in co-educational schools. It is hoped that research into these aspects of analogy use will contribute to an understanding of why the majority of students in high schools in Kenya are reluctant to take physics. Our young girls in high schools are not attracted to physics. Any teaching and learning approaches that can contribute to the effort to reverse this trend are welcome. Understanding of these issues may also lead,
eventually, to improved student enrolment in physics-related courses at Kenyan universities and middle level colleges.

**Summary**

It is anticipated that this study will inform physics teaching and curriculum development in Kenya, and in other countries with similar background. It may also have value for those working in multicultural classroom settings in Western countries. The findings will be of interest and use to those other physics teachers who may want to improve and enrich their physics teaching practices.

The study also adds to the list of informative studies by exposing some of the unique analogies and their effects on the teaching and learning of physics in Kenya. WWA, TWA and GMAT models can be used to assess the suitability and completeness of analogies before they are presented to students. Doing so in advance of instruction can enable the teachers to familiarise themselves with areas of conceptual conflict and prepare, in advance, appropriate instructional activities aimed at resolving the conflicts. This way, environmental analogies will be more successful and will contribute to the effort of attracting more students to physics. This is crucial in Kenya, where the subject is not popular with the majority of Kenyan high school students even though the subject is very useful in terms of future career choices.

Most of the analogies captured during the observation phase were
spontaneously generated, save for the few which were planned, such as the water tank/reservoir analogy. In general, the analogies were anthropomorphic and environmental (cultural) in nature.

Students who participated in the study were given a test on analogously taught concepts. From their written responses, alternative conceptions were discerned. These alternative conceptions exhibited the following characteristics:

(i) Interpreting technical science language literally;
(ii) Interpreting preconceptions in terms of incoming information;
(iii) Transferring misconceptions from one domain to another, hence affecting meanings of related concepts in subsequent domains
(iv) Misconceptions constructed from experience were difficult to undo and tended to persist even in the presence of correct information.

Limitations of the Study

Like any other study, this study has its limitations in methods and findings. Narrative description, a key method in this study, has limitations in the way it is used. As Stallings and Mohlman (1988) point out, "... for most, the terms used to describe the observed phenomena are the observer's natural words" (p.472). As a consequence, authentic description of the use of analogies depended on the observer's theoretical understanding, professional expertise and level of accuracy. Tied to this method was the skill of note-taking. Because note taking can be regarded by some teachers as an intrusion in their classrooms, detailed
field notes were written up from memory immediately after the lesson observation (Stenhouse, 1988). Thus, the accuracy and quality of data obtained largely depended on how much the researcher remembered; a limitation that led to the deployment of audio and video recording for review after lessons or school.

Observer biases, to which the researcher was no exception, may inevitably have filtered through. But the fact that the researcher was aware of the bias was, in itself, a safeguard. In other words, generations or conclusions regarding the study were based on the data at hand, the accuracy of which was corroborated with information from the teachers and students by way of informal interviewing. In addition, class textbooks and schemes of work (unit plans) that the teachers used were examined.

Studies dealing with humans are always delicate. Unpredictably, the moods of the subjects can change and even the fact that the subjects are aware that they are being observed can distort the quality of data. These effects were minimised by the researcher maintaining good rapport with the teachers and undertaking an extensive teaching commitment.

It should be noted that the case of alternative conceptions or frameworks is based on outcome of a single test and therefore requires further probing. What has been analysed came out of the teachers’ routine testing and became of interest to the researcher since it in a way reflected on the kind of teaching tools (particularly environmental analogies) the teachers used.
Therefore, the discussion and suggestions on the subject of alternative frameworks should be understood in the context of this study. However, the study opens up an area that would require extensive investigation for more understanding of the effect environmental analogies may have on students’ understanding of analogically taught concepts.

Being a case study, the generalisations, assertions, claims and conclusions are safely within the bounds of the study; a fact recognised by Simons (1989) when she says that case studies “… allow judgements to be made in relation to particular circumstances and clienteles …” (p.115). Thus, any conclusions, inferences and generalisations are case specific. They should not be taken to apply to all physics classes in Kenya. But like any other case study, the information gained is useful in understanding other such classrooms whenever and wherever they are encountered.
References


Erickson, F. (1994). Qualitative research methods on teaching. In M. Wittrock (Ed.), *Handbook of research on teaching* (pp.119 - 161). New York: Macmillan.


Appendix 1

ETHICAL REVIEW PROTOCOL

To be completed by the principal investigators for all studies which

- involve the use of human subjects, and/or
- involve the analysis of data collected from/ on human subjects where such data are not in the public domain.

Title of Project/Thesis: Using Analogies in Teaching and Learning School Physics: A Case of Kenyan Classroom

Principal Investigator(s) or Student and Faculty Supervisor: Samson Madrana Nchwon and Prof. Derek Hudson

Department in which project/thesis will be housed: Curriculum, Teaching and Learning (CTL)

Objectives of Study:

1) To be able to identify analogies Kenyan teachers use in teaching physics concepts to form 2 (grade 10) students.

2) To analyse the analogies for suitability using Glyn's model of Teaching With Analogies (TWA) model.

3) To bring to surface students' conceptions of the analogous targets and the analogies.

1. Data Collection.

(a) What data are being collected? (achievement scores, attitude scores, experimental test results, etc.)

Analogous targets, topics, analog attributes, target attributes, similar analog-target attributes, dissimilar analog-target attributes, students' conceptions of analogies used, target, misconceptions, local analogies, universal analogies, spontaneously generated analogies and teachers' reasons for using analogies.

(b) How will the data be collected? (Survey, questionnaire, structured interviews, observation, participant observation)

Observing physics classes, informal interviews with the teachers and students, examining main class text teachers' lesson plans and schemes of work, and the syllabus, students' note books.
(c) Procedures: Please outline procedures to be followed in (a) and (b) above.

1) Observe every physics lesson in order to identify any analogies used.

2) Record the analogies. Tape record the whole class discussion.

3) Have informal discussion with the teachers and some students during off task or break about what transpired in the lessons.

(d) Instruments: please list all questionnaires, tests, observation schedules, interview schedules, etc. to be used. Attach copies where possible.

The observation will be from May 3, 1999 to August 5, 1999 (12 weeks) with 5-40 min lessons weekly.

(e) Indicate what information will be taken from existing records (e.g. school records, hospital records).

N/A

2. Subjects

(a) Describe the subject population and give the age/grade level and the affiliation as appropriate (e.g., school, university/college students, school board employees, hospital employees, members of the public). Indicate the number of subjects to be included in the study.

The subjects are form 2 (grade 10) high school students in one of the national schools in Kenya. They are from various ethnic communities in Kenya. National schools operate a quarter system of student enrollment. Three form 2 classes taught by different teachers will be used. The total number of students involved in the study will be 120 (each class has 40 students).

(b) How will the subjects be selected for inclusion in the study?

Selecting the school automatically implies the subjects. The national school has been selected because of its mixture of diverse ethnic or cultural groups of students. It is also accessible and has good science facilities. It therefore offers physics. It is large enough to have at least three physics classes of the same grade level with adequate staffing in the subject. Moreover, the school principal and the teachers are willing to allow me to conduct the research.
3. **Data Access, Uses and Interpretation**

(a) Who will have access to the raw data?

*The researcher (myself) and the participating teachers.*

(b) How will confidentiality and/or anonymity of the raw data be maintained? (e.g., will names be deleted and replaced by codes known only to the investigators; will data be stored in locked files?)

*All names, including the name of the school, class, students, teachers, principal will be pseudo-names.*

*Even during the recording of data, pseudo-names will be used.*

(c) What disposition will be made of the raw data at the end of the study? (e.g., to be stored in data archives.)

*The raw data will be locked in a safe custody for long enough period, after which I will discard them. Since all names will be pseudo-names, this will serve as a way of ensuring confidentiality even long after the study.*

(d) What feedback will be given to subjects and/or to those individuals who provided informed or administrative consent?

*According to the Kenyan requirements, a copy of the approved thesis is given to the library in the Office of the President, the school, and the teachers. The teachers will have to view the tapes on screen for approval.*

(e) What steps will be taken to maintain anonymity of subjects and test sites in written reports?

*Written reports will bear pseudo names for subjects and test sites.*

(f) What steps will be taken to alert participants to possible evaluative interpretation and to give them an opportunity to withdraw from the study? (By evaluative interpretation is meant, for example, the indirect evaluation of a teacher's professional performance or of a student's academic performance, as a result of participating in the study, where such evaluation is not an objective of the study).

*The study is not about evaluation of individual teachers but analysis of analogies and students' conceptions of analogous and target concepts. However, before such an act is taken, the researcher will discuss with the subjects concerned and assurance of anonymity provided. But I intend to avoid any kind of individual teacher or student performance evaluation. The students and the teachers will be informed that they will be free to withdraw from the study if they so wished.*
4. Informed Consent

(a) Will informed consent be obtained from all participants?
   Yes ___  No ___ X

(b) Will administrative consent be obtained?
   Yes ___ X  No ___

(c) What steps will be taken to obtain individual informed consent and/or administrative consent?

   Before I start observation, I will have gained mutual consent from the three participating teachers, the
   school principal and a permit to conduct research in Kenya from the Office of the President of the
   Republic of Kenya. PLEASE REFER TO THE ATTACHED APPENDIX I OUTLINING RESEARCH,
   PROCESS IN KENYA.

(d) Will the informed consent be written? Yes ___ X  No ___
   If not, why not?

   The only written consent will be from teachers, the principal and the permit from the OP. The students in
   Kenya are under the care of the principal and the class teachers. Consent by the principal and the teachers
   implies includes consent by the students. However, usually students are informed of the whole process.

(e) What information will be given to subjects and/or others who are providing informed consent?
   Please attach a copy of each letter to be sent to potential participants. This letter should describe the
   study in lay terms, outline potential benefits/risks to participants, indicate that participants are free to
   withdraw at anytime, from possible evaluation on the basis of the written report.

   Administrative Consent

   Administrative consent may be deemed sufficient:

   a) for studies which have as their intent and focus the acquisition of statistical information and where
      the collection of data presents

      (i) no invasion of personal privacy;

      (ii) no potential social or emotional risk;

   b) for studies which have as their intent and focus the development and evaluation of curriculum
      materials, resources, guidelines, test items and program evaluation rather than the observation and
      evaluation of persons as individuals.

   Signature of investigator(s) ________________________________
   Date: 30/3/1999

   Student Name: [Signature]
ETHICAL REVIEW: STATEMENT FROM COMMITTEE MEMBERS

Title of Project / Thesis: Using analogies in teaching and learning school physics: A case of Kenyan classroom.

Principal Investigators (if Research):


1. Does the study present any risks for subjects / participants?
   Yes ___X___ No _____. If Yes, please outline the nature of the risks.
   There are potential concerns about confidentiality.

2. Is the risk justified in terms of the potential benefits of the study?
   Yes ___X___ No ______

3. Does the study involve procedures which may result in the invasion of the personal privacy of the participants / subjects?
   Yes ___X___ No ______

   IF THE PROPOSED STUDY INVOLVES ANY POTENTIAL RISKS AND/OR ANY POSSIBLE INVASION OF PRIVACY, THE INFORMED CONSENT OF PARTICIPANTS MUST BE OBTAINED.

4. What type of consent does the researcher intend to obtain?
   ___X___ individual, informed consent
   ___X___ administrative consent
   ______ individual consent is not necessary

   Is this adequate? Yes ___X___ No ______
   If No, what level of consent should be obtained?
   Not applicable.
5. Has the researcher provided adequate information on the procedures to be used in obtaining consent?

Yes ___X__ No _____

If No, what additional information is needed?

Not applicable.

6. Are the procedures for obtaining consent acceptable and do they adequately protect the rights of the subject?

Yes ___X__ No _____

If No, please indicate what changes to the procedures should be included.

Not applicable.

7. Is the information to be given to those providing informed consent sufficient?

Yes ___X__ No _____

If No, please specify what additional information should be provided for subjects.

(Note: In order to provide informed consent, potential subjects should be given information on the nature of the study, the potential risks/benefits of participation, the safeguards to be taken to maintain confidentiality of data and to protect participants from possible evaluation and should be advised that they are free to withdraw from the study at any time).

8. Please outline any additional safeguards which should be introduced.

Not applicable.

9. Is an additional review necessary to verify that the revisions you have requested in Questions 4, 5, 6, and 7 or the additional safeguards outlined in Question 8, have introduced?

Yes _____ No _____
Not applicable.

If Yes, please indicate when this review should take place.

_____ Prior to initiation of study
_____ Other (please specify)

10. If the nature of this study in such that research instruments (e.g., questionnaires) and/or research materials (e.g., curriculum materials) will be developed during the course of the project, should an ethical review be undertaken prior to the use of the instruments and/or materials with subjects?

Yes _____ No _____

If yes, please indicate which instruments / materials should be forwarded to the Ethical Review Committee, and at what stage of the project.

Not applicable.

11. In your opinion, does this proposed study present any unusual risk for the researcher or the Institute? Please specify.

No:

Signature of Committee Member   Name (please print)   Date

Apr. 9, 1999
ETHICAL CERTIFICATE

Project/Thesis Title:  Using Analogies in Teaching and Learning School Physics: A Case of Kowama Classroom

Principal Investigator (if Research)
Student and Thesis Supervisor (if Thesis): Sowombo Modesta Nathan and Prof. Derek Hodson

Ethical Review Committee Members:
Chair
Prof. Erminia Pedretti

Prof. Brent Kibbauer

Prof. Jim Hewitt

This certificate is completed in the light of relevant OISE/UT policy on legal, ethical and moral review, taking into account the relevant standards of the discipline concerned as well as, where appropriate, the standards specified by certain external funding bodies.

This is to certify that the above noted committee has examined this research and development project and concludes that the research meets accepted professional standards for the conduct of research prevailing within the discipline(s) involved including appropriate standards of ethical acceptability.

[Signature]
Signature of Chairperson
Ethical Review Committee

[Date]
April 13/99

Except that the following measures must be taken to ensure conformity with such standards. (Please specify and indicate if further review is required).

[Signature]
Signature of Chairperson
Ethical Review Committee

[Date]
April 13/99
Appendix 2a

OFFICE OF THE PRESIDENT

[Telegraphic Address: "Kenya"
Telephone/Telex: 5729331
Officially used in official capacities
Ref. No. 0P/13/001/29C 56/2

6th May 1999]

[Signature]

[Address]

[Date]

Dear Sir,

RESEARCH AUTHORIZATION

Please refer to your application for authority to conduct research on "Using analogies in teaching and learning school Physics: A Case of Kenyan Classroom." I am pleased to let you know that your application has been considered and approved and accordingly you are authorized to conduct research in Kiambu District as from 6th May, 1999 to 30th August, 1999.

You are advised to pay a courtesy call on the District Commissioner, Kiambu before embarking on your research project. You are further advised to avail two copies of your final research report to this office upon completion of your research project.

Yours faithfully,

[Signature]

[Name]

[Position]

[Office/Provincial Administration]

[cc: The District Commissioner, Kiambu]
Appendix 2c

OFFICE OF THE PRESIDENT

6th May 1999

Samson Rashon Madera,
Jomo Kenyatta Foundation,
P.O. Box 30533,
Nairobi.

Dear Sir,

RESEARCH AUTHORIZATION

Please refer to your application for authority to conduct research on "Using analogies in teaching and learning school Physics: A Case of Kenyan Classroom". I am pleased to let you know that your application has been considered and approved, and accordingly, you are authorized to conduct research in Kiambu District as from 6th May, 1999, to 30th August, 1999.

You are advised to pay a courtesy call on the District Commissioner, Kiambu, before embarking on your research project. You are further advised to avail two copies of your final research report to this office upon completion of your research project.

Yours faithfully,

[Signature]

J. E. [Name]

FOR: PERMANENT SECRETARY/ PROVINCIAL ADMINISTRATION

cc: The District Commissioner,
Kiambu.