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WESTERN CAPE**

Title of Thesis: An analysis of pre-service teachers' ability to use a dialogical argumentation instructional model to solve mathematical problems in physics

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DECLARATION

I declare that “*An analysis of pre-service teachers’ ability to use a dialogical argumentation instructional model to solve mathematical problems in physics*” is my own work; that it has not been submitted before for any examinations or degree purposes in any other university, and that all sources I have used or quoted have been indicated and acknowledged by complete references.

Paul N. Iwuanyanwu

Signed: Date:



DEDICATION

Experience shows it takes a little bravery to write a dissertation. This dissertation is dedicated to my late sisters Chinazunwa and Ugochi Iwuanyanwu whose untimely death nearly halts this dissertation from seeing its fruition, and to my bereaved and bravest parents Dr. & Mrs. F. Iwuanyanwu.



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A man only begins to be a man when he ceases to accuse others as the cause of his condition, and builds himself up in strong and noble thoughts; ceases to kick against circumstances, but begins to use them as aids to his more rapid progress, and as a means of discovering the hidden powers and possibilities within himself. Only by much searching and mining are gold and diamonds obtained, and a man can find every truth connected with his being, if he will dig deep into the mine of his soul. That he is the maker of his character, the molder of his life, and the builder of his destiny, he may unerringly prove, if he will watch, control, and alter his thought, tracing their effects upon himself, upon others and upon his life and circumstances, linking cause and effect by patient practice and investigation. In this direction, as in no other, is the law absolute that “He that seeks finds; and him that knocks it shall be opened.” For only by patience, practice, and ceaseless importunity can a man enter the door of the temple of knowledge—James Allen.

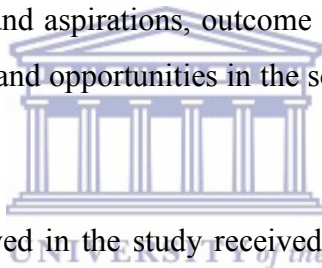
Dr. Oscar Koopman introduced me to science education research seven years ago, so it seems appropriate to thank him first. Throughout my time in post-graduate studies (Hons.), he has managed to be both my teacher and my colleague—quite a rare superposition of states. I have never seen Oscar too busy to talk, too busy to help, or too busy to encourage, and I can’t thank him enough. I am forever indebted to my supervisors Prof R. Govender and Professor M. Ogunniyi for their tireless efforts in nurturing me. Thanks for investing in my life, in humility I will pass on the outcome forward to generation in my sphere of contact.

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The researcher, of course, alone is responsible for all errors, opinions, conclusions, or recommendations expressed in this dissertation.

ABSTRACT

This study chronicles a teacher training education programme. The findings emerged from the observation of argumentation skills employed by students in a physical science education classroom for pre-service high school teachers. Their task was to use the nature of arguments to solve mathematical problems of mechanics in a physics classroom. Forty first-year students were examined on how they used a dialogical argumentation instructional model (DAIM) based on Toulmin's (1958/2003) Argument Pattern (TAP), Downing's (2007) Analytical Model (DAM) and Ogunniyi's (2007a & b) Contiguity Argumentation Theory (CAT) to solve mathematical problems in physics. Thus efforts to judge the pre-service teachers' capability to solve mathematical problems in physics with respect to mechanics were compounded by the demand for the inclusion of a self-efficacy framework. According to Bandura (2006) self-efficacy is the judgment of capability. Self-efficacy plays a key role in human functioning in that it affects not only people's behaviour but other issues such as goals and aspirations, outcome expectations, affective proclivities and perception of impediments and opportunities in the social environment (Bandura, 1995, 1997 & 2006).



The pre-service teachers involved in the study received training and feedback on how to construct scientific reasoning and to express proficiency in advancing solutions to problems. They also received training and feedback in critiquing and justifying claims that connect the use of math-in-physics. The pre-service teachers were divided into small groups compatible with those in the dialogical argumentation instructional model (DAIM). After training in small groups, each group received tasks that required the transfer of skills to new math-in-physics problems. These required a different form of argumentation. It was hoped this would reveal how this process affects their self-efficacy. The process was repeated for a period of six months during which further training was provided.

The data collected included the PSAT, interviews, and excerpts of video-recorded in-class observation together with an analysis of the quality of the arguments they produced in their written essays. The data set was analyzed using the argumentation framework of the CAT, TAP and Downing 2007 model. In the math-in-physics problems solved by groups in the DAIM setting, it was found that during their analysis of any particular problem, the groups who created conceptual resources of elements in arguments showed a better understanding

of the problem, presented their work more thoughtfully and argued better than those who had not. Many of the pre-service teachers demonstrated fallacy in their reasoning, for example, by appealing to ignorance, tradition or authority while making faulty analogies, by identifying wrong causes, or by resorting to kettle logic, and the quantification of fallacy. Such fallacies were found to be prevalent in the beliefs of pre-service teachers. This maybe attributable to their commonsensical grasp of what constitutes knowledge, or alternatively it may represent scientific poverty.

As observed, when rebuttal increased on some of the Newtonian concepts tested in the PSAT instrument, many of the pre-service teachers became dissatisfied with their existing notions. The overall results tend to suggest that the treatment (DAIM) had the effect of improving pre-service teachers' ease and confidence, and hence their ability to use the essential features of the dialogical argumentation instructional model (DAIM) to mobilise mathematical concepts needed in the solution of mechanical physics problems. Also, the transfer of math-in-physics problem-solving skills was best displayed in small group activities rather than in individual PSAT activities. The basis for this seemed set in the use of arguments as a scaffold for transferring learning. Over time the pre-service teachers had improved their ability to consciously use arguments to solve math-in-physics mechanics problems for example, that of motion in two dimensions. Of all the sources of self-efficacy tested only mastery experiences positively predicted the pre-service teachers' math-in-physics self-efficacy. Together with uniqueness indicators, mastery experiences accounted for a degree of variance between male and female pre-service teachers.

Key words: pre-service teachers, Toulmin argumentation pattern (TAP), school science, Physical Science Achievement Test (PSAT), dialogical argumentation instructional model (DAIM), knowledge construction, contiguity argumentation theory (CAT), self-efficacy, physical science, curriculum, mathematics.

ACRONYMS and ABBREVIATIONS

| | |
|-------|--|
| CAPS | Curriculum and Assessment Policy Statement |
| CAT | Contiguity Argumentation Theory |
| DAIM | Dialogical Argumentation Instructional Model |
| DAM | Downing Analytical Model |
| DoE | Department of Education |
| FBD | Free-Body Diagram |
| FET | Further Education and Training (Grades 10-12) |
| FP | Foundation Phase |
| GET | General Education and Training (Grades R-3) |
| GCEA | Group Constructing and Evaluating Argument |
| IFDSE | Instrument For Determining Self-Efficacy |
| ISP | Intermediate and Senior Phase (Grades 4-9) |
| NCS | National Curriculum Statement |
| O | Observation or measurement |
| PSAT | Physical Science Achievement Test |
| TAP | Toulmin Argument Pattern |
| RNCS | Revised National Curriculum Statement |
| SIKSP | Science and Indigenous Knowledge Systems Project |
| WCED | Western Cape Education Department |
| X | Intervention programme (or treatment) |

DEFINITION OF TERMS

For the purpose of enhancing precision in this research, researchers used operational definitions. Important concepts are thus defined in terms of measurable events that produce them or are characteristic of them. This study recognizes the fact that pre-service science teachers come to class with prior knowledge gained from previous schooling, home, peers and the social environment also known as everyday science.

Argumentation

a. This is defined as the process of making a claim and using evidence to provide a justification for the claim (Kuhn & Udell, 2003).

b. Dialogical Argumentation Instructional Model (DAIM) This is a model designed to engage learners in scientific argumentation so as to develop complex reasoning and critical thinking skills. Its function is to enable learners to understand the nature and development of scientific knowledge, to improve their communication skills and to facilitate the achievement of collaborative consensus on a given subject (Ogunniyi, 2007a).

c. Conceptual Change

In a general sense, conceptual change enriched by constructivist perspectives on learning is characterized as the building of new ideas in the context of old ones through partial or major restructuring of already existing knowledge, concepts or schemata (diSessa, 2006).

d. Indigenous Knowledge

Indigenous Knowledge refers to intricate knowledge acquired over generations by communities as they interact with the environment. Indigenous knowledge (IK) is local knowledge – knowledge that is unique to a given culture or society (Ogunniyi, 2004; Ziman, 2000).

e. Misconceptions

According to Ben-Ari (2001) a constructivist would see a misconception held by the learner as logical construction based on a consistent though non-standard theory, and not as a slip or (trivial) mistake.

f. Constructivism

Vygotsky's (1978) view of constructivism is that knowledge is constructed by individuals and so social interaction is a fundamental aspect of the development of cognition. His belief is that everything is learned on two levels: first, through interaction with others and then through integration into the individual's mental structure. This forms the premise of my study.

g. The Physical Science Achievement Test

This is a test developed to measure the nature of argumentation strategies that pre-service science teachers use to solve selected mathematical problems in physics and their sense of self-efficacy.



TABLE OF CONTENTS

| | |
|--|-----------|
| TITLE OF THESIS | i |
| DECLARATION | ii |
| DEDICATION | iii |
| ACKNOWLEDGEMENTS | iv |
| ABSTRACT | v |
| ACRONYMS and ABBREVIATIONS | vii |
| DEFINITION OF TERMS | viii |
| LIST OF TABLES | xvi |
| LIST OF FIGURES | xvii |
| Preamble: Scientific Conceptions That Mock Reality- Argumentation as Coming-To-Knowing | xix |
| | |
| CHAPTER ONE | 1 |
| Prologue | 1 |
| 1.0 Positioning Myself as a Researcher | 1 |
| 1.1 Introduction | 5 |
| 1.2 Curriculum reform in South African Basic Education: Tracking Changes | 7 |
| 1.3 Synopsis of South African physical science curriculum for Grades 10–12 | 9 |
| 1.4 Teaching, learning and assessment of physical science education at the institution under study | 10 |
| 1.5 Challenges facing school science and mathematics in South Africa | 11 |
| 1.6 Rationale for the study | 12 |
| 1.7 Research purpose | 13 |
| 1.8 Problem statement | 14 |
| 1.8.1 Concern that one problem may lead to another: Mathematics education an elective for physical science pre-service teachers | 15 |
| 1.9 Significance of the study | 20 |
| 1.10 Theoretical Framework | 21 |
| 1.10.1 Entrance for the present study into Argumentation paradigm | 21 |
| 1.10.2 Understanding the Contiguity Argumentation Theory (CAT) | 22 |
| 1.11 Delimitation of the study | 23 |
| 1.12 Overview of the Study | 24 |
| 1.12.1 Chapter One: Research Problem and its setting. | 24 |
| 1.12.2 Chapter Two: Review of related literature | 24 |
| 1.12.3 Chapter Three: Research design and methodology | 24 |
| 1.12.4 Chapter Four: Data presentation, analysis and discussion | 25 |
| 1.12.5 Chapter Five: Summary, implications and reflections | 25 |
| | |
| CHAPTER TWO | 26 |
| LITERATURE REVIEW | 26 |
| Prologue | 26 |
| 2.0 Introduction | 26 |
| 2.1 Argument and Argumentation skills | 26 |
| 2.1.1 Definitions | 26 |

| | | |
|----------------------|---|-----------|
| 2.2 | Is teaching argumentation skills important for students learning of science? | 27 |
| 2.3 | Students find it difficult to engage in dialogical Argumentation | 29 |
| 2.3.1 | Addressing difficulties students find to engage in a dialogical Argumentation | 31 |
| 2.3.2 | Reasoning and Arguments | 34 |
| 2.4 | Argumentation Theories and their connections to this study | 35 |
| 2.4.1 | Standards for evaluating arguments | 37 |
| 2.5 | Deficiencies of Toulmin's Argument Pattern (TAP) | 38 |
| 2.6 | Theoretical versus Practical Arguments | 39 |
| 2.7 | Modelling Conceptual Change through Argumentation Process | 41 |
| 2.7.1 | Conception, misconception and conceptual change | 43 |
| 2.8 | Difficulties various studies have encountered using TAP and some useful suggestions | 45 |
| 2.9 | The Contiguity Argumentation Theory CAT | 52 |
| 2.9.1 | Five Adaptive Cognitive States of CAT | 53 |
| 2.10 | Argumentation in classroom, writing, constructing and evaluating arguments | 55 |
| 2.11 | Studies done in some Universities in South Africa relevant to the present study | 56 |
| 2.12 | Cognitive ability processes and Problem recognition | 61 |
| 2.12.1 | Cognitive Processes for Retention and Transfer of learning | 62 |
| 2.13 | Socio-cultural Constructivism | 63 |
| 2.14 | Teachers and students still face challenges with math-in-physics problem-solving | 65 |
| 2.15 | Language perspective in learning physics as applied in the study | 68 |
| 2.16 | Self - Efficacy | 69 |
| 2.17 | A model of self-efficacy-performance relations | 70 |
| 2.18 | Summary | 73 |
| CHAPTER THREE | | 75 |
| METHODOLOGY | | 75 |
| 3.0 | Introduction | 75 |
| 3.1 | Sample | 75 |
| 3.1.1 | Determining the sample | 76 |
| 3.2 | Demographic Characteristics of the research participants | 78 |
| 3.3 | Research design: The case study approach | 79 |
| 3.3.1 | One group time series Design | 80 |
| 3.4 | Research procedures | 81 |
| 3.5 | Instrumentation: | 82 |
| 3.5.1 | Rationale for merging Quantitative and Qualitative methods | 82 |
| 3.5.2 | Data consideration in case study | 83 |
| 3.5.3 | Development of instruments for the study | 84 |
| 3.5.4 | Considering Language while developing instruments | 84 |
| 3.5.5 | Data sources: Physics mechanics I | 85 |
| 3.6 | Validity and Reliability | 86 |

| | | |
|---|--|------------|
| 3.7 | Piloting of the study | 87 |
| 3.8 | The Dialogical Argumentation Instructional Model (DAIM) | 88 |
| 3.8.1 | How the five stages of DAIM embraces self-efficacy and assessment of tasks | 90 |
| 3.8.2 | The central aim of DAIM | 91 |
| 3.8.3 | Implementation of DAIM as an instructional discourse | 92 |
| 3.9 | Paucity in Students' math-in-physics reasoning: Concerns emerged after study was piloted | 94 |
| 3.10 | Exploring observation (O1) Data Collection and the Challenges experienced | 95 |
| 3.11 | A Description of math-in-physics Mechanics Problem Taught & Examined | 96 |
| 3.12 | Teaching and confronting mathematical problems in physics | 98 |
| 3.12.1 | Overly procedural thinking towards math-in-physics problem-solving | 100 |
| 3.12.2 | SOLUTION to Question 2: Calculate the magnitude of the acceleration of the wagon- engine combination. | 102 |
| 3.13 | Training first year pre-service teachers on how to construct, write, and evaluate arguments in DAIM setting | 105 |
| 3.14 | Training Pre-service teachers on Talking and Listening skills during argumentation discourse | 107 |
| 3.15 | Individual and Group PSAT activities in DAIM learning environment | 108 |
| 3.16 | Data collection and its Procedure | 110 |
| 3.17 | Procedure for determining Effectiveness of DAIM in the study | 111 |
| 3.18 | Tertiary Classroom Observation | 112 |
| 3.19 | Field notes and Challenges faced in the study | 113 |
| 3.20 | Interviews | 114 |
| 3.20.1 | Preliminary interview happened during Pre-service teachers' exam revision | 114 |
| 3.20.2 | Main interview | 116 |
| 3.21 | Data Analysis | 117 |
| 3.21.1 | Analytical Framework | 117 |
| 3.21.2 | Modification of analytical framework- DAM | 119 |
| 3.21.3 | Modification of analytical framework- CAT | 121 |
| 3.21.4 | Analytical definition of the use of nature of arguments in the study | 122 |
| 3.22 | Statistical Data Analysis | 122 |
| 3.23 | Ethical considerations | 123 |
| 3.24 | Summary | 124 |
| CHAPTER FOUR | | 125 |
| PRESENTATION OF FINDINGS AND DISCUSSIONS | | 125 |
| 4.0 | Introduction | 125 |
| 4.1 | RESEARCH QUESTION 1: What types of argumentation strategies did the pre-service science teachers use in solving selected mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model? | 126 |
| 4.2 | Pre-service teachers' performance on PSAT at observations (O3 and O4) | 130 |

| | | |
|--------|---|-----|
| 4.3 | Possible impact of DAIM on Pre-service teachers' performance on PSAT | 132 |
| 4.4 | Individual versus Group math-in-physics problem-solving (including observation made from the classroom video-camera) | 133 |
| 4.5 | Pre-service teachers' dialogical argumentation by level | 136 |
| 4.5.1 | Item 3 reads: Everything that moves will eventually come to a stop. Being at rest is the "natural" state of motion of all objects. | 136 |
| 4.5.2 | Item 3.2: If agree (with item 3), state why? If disagree, state why? | 137 |
| 4.5.3 | Item 3.3: One of your classmates may disagree with you. What might their alternative be? | 137 |
| 4.5.4 | Item 3.4: Explain why you would accept or discard your classmates alternative view(s) about the claim | 138 |
| 4.6 | Interpretative Commentary | 138 |
| 4.7 | How pre-service teacher PT15 used the Newton's Second law equation while calculating mathematical problems in physics (Item 3.6.2) | 142 |
| 4.8 | Holding misconception of physics principle side-by-side with correct mathematical calculations in 2D mechanics problems | 144 |
| 4.9 | PT28's case: Mathematical competencies and other conceptions for problem-solving in physics | 147 |
| 4.10 | Item 4: A continuous force is needed for continuous motion – Pre-service teachers' responses | 150 |
| 4.11 | Small Group presentation- Item 6 on gravity: A hammer and a feather | 153 |
| 4.11.1 | Gravitational influence on a hammer and a feather | 154 |
| 4.12 | Frequency of Instances: Individual constructed, wrote and evaluated arguments (Item 5) | 157 |
| 4.12.1 | Item 5.1: Do you agree or disagree with this notion? | 158 |
| 4.12.2 | Item 5.2: If agree, state why? If disagree, state why? | 158 |
| 4.12.3 | Item 5.3: One of your classmates may disagree with you. What might their alternative be? | 159 |
| 4.12.4 | Item 5.4: Explain why you would accept or discard your classmate's alternative on (item 5.3). | 159 |
| 4.13 | Distribution of pre-service teachers' levels of argumentation | 161 |
| 4.14 | Interpretative Commentary | 162 |
| 4.15 | How pre-service teachers demonstrated their argumentation skills during group presentation on math-in-physics problem-solving | 164 |
| 4.16 | Interpretative Commentary | 166 |
| 4.17 | Transformation in qualitative thinking exhibited by PT22 during problem-solving of item 6.3.1. | 169 |
| 4.18 | Unresolved anomalies encountered by pre-service teacher PT13 while using the nature of arguments as strategy to solve mathematical in physics | 170 |
| 4.19 | Demonstration of problem-solving strategy using nature of arguments- Pre-service teacher (PT39, group A) | 171 |
| 4.20 | Interpretative Commentary | 172 |
| 4.21. | RESEARCH QUESTION 2: How effective is DAIM in enhancing pre-service science teachers' ability and sense of self-efficacy to solve selected | |

| | |
|--|-----|
| mathematical problems in physics? | 174 |
| 4.22 Gain Scores on math-in-physics problems: DAIM versus Lecture methods of teaching. | 176 |
| 4.23 Effectiveness of DAIM: Pre-service teachers responses | 177 |
| 4.23.1 Diverging Stacked Bar Charts | 178 |
| 4.24 Second part of the Research Question 2: Self-efficacy | 179 |
| 4.24.1 Presentation of results | 180 |
| 4.25 Interpretative Commentary | 181 |
| 4.26 Self-efficacy: Individual-group attributes & performances | 182 |
| 4.27 Tertiary Science Classroom Observation | 183 |
| 4.27.1. Discussion on pre-service teachers' argumentative skills and trains of reasoning towards construction of knowledge to solve math-in-physics problems | 184 |
| Small group argumentation on Scenario 1 | 184 |
| 4.27.2 What is your view about the suggestion Aviwe's father gave in terms of your scientific understanding? (Item 1.1) | 185 |
| 4.27.3 One of your classmates may disagree with you. What might their alternative be? (Item 1.2) | 186 |
| 4.27.4 What would you reply to your classmate to explain your position is right? | 186 |
| 4.27.5 Interpretative Commentary | 187 |
| 4.27.6 Scenario 2: Group constructed, wrote and evaluated arguments | 189 |
| Small group argumentation on Scenario 2 | 189 |
| 4.27.7 Which of your twin siblings do you agree with in terms of your scientific understanding? Amanda () Jim () State why. | 189 |
| 4.27.8 One of your classmates may disagree with you. What might their alternative be? | 190 |
| 4.27.9 What would you reply to your classmate to explain your position is right? | 191 |
| 4.28. Interpretative Commentary | 192 |
| 4.29 Interview | 193 |
| 4.29.1 Interview Question 1: How have your experiences in the DAIM based-lectures improved your ability in using the nature of arguments to solve mathematical problems in physics mechanics? | 194 |
| 4.29.2 Interpretative Commentary | 195 |
| 4.29.3 Follow-up question 1.1: Do you think the DAIM has equipped you on how to tap into qualitative understanding of math-in-physics problems using the nature of arguments before applying algebraic manipulation? | 198 |
| 4.29.4 Interpretative Commentary | 202 |
| 4.29.5 Follow-up question 1.2: What would you say are the positive and negative aspects of the use of DAIM as an instructional approach? | 204 |
| 4.29.6 Interpretative Commentary | 206 |
| 4.30 Interview Question 2.1: How confident and ease are you now with math-in-physics problem-solving compare before the intervention programme (DAIM)? | 207 |

| | |
|---|------------|
| 4.30.1. What is/are the reason(s) for your response? | 207 |
| 4.31 Interpretative commentary | 209 |
| 4.32 Summary of findings | 211 |
| 4.32.1 Findings related to pre-service teachers use of argumentation as problem-solving strategies | 211 |
| 4.32.2 Findings related to the effectiveness of the intervention programme | 213 |
| 4.32.3 Challenges faced by individual groups to use the nature of arguments in DAIM setting | 214 |
| 4.32.4 Findings related to challenges pre-service teachers grapple with to construct, write and use argument during problem-solving | 215 |
| 4.33 Fallacies in reasoning- Processes of arguments followed by pre-service teachers | 215 |
| 4.33.1 Appeal to Ignorance | 216 |
| 4.33.2 Faulty Cause | 216 |
| 4.33.3 Kettle Logic | 216 |
| 4.33.4 Quantification Fallacy | 217 |
| 4.33.5 Straw Man | 217 |
| 4.33.6 Appeal to Tradition | 218 |
| 4.34 Findings from interview items | 219 |
| 4.35 Paucity of the group use of nature of arguments | 219 |
| 4.36 Summary | 220 |
| CHAPTER FIVE | 223 |
| IMPLICATIONS, CONCLUSION AND RECOMMENDATIONS | 223 |
| 5.1 Introduction | 223 |
| 5.2 Major findings and how they answered my research questions | 223 |
| 5.2.1 Research question 1: What types of argumentation strategies did the pre-service science teachers use in solving mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM)? | 223 |
| 5.2.2 Research question 2: How effective is DAIM in enhancing the pre-service science teachers' ability and sense of self-efficacy to solve mathematical problems in physics? | 224 |
| 5.3. Implications of the findings to teaching and learning of science | 224 |
| 5.3.1 Implication for Teacher education | 225 |
| 5.3.2 Implications for Policy and Teachers | 226 |
| 5.3.3 Implications of findings for teaching math-in-physics problem solving | 227 |
| 5.4 Limitations of the study | 228 |
| 5.6 Conclusion | 230 |
| 5.7 Recommendations | 231 |
| REFERENCES | 235 |
| APPENDICES | 258 |

LIST OF TABLES

| | |
|--|-----|
| Table 1.1 Proportions of core and elective subjects in each year of Further | 16 |
| Table 2.1 The main features of TAP as espoused by Toulmin | 48 |
| Table 2.2 Downing (2007) Analytical model of argumentation | 49 |
| Table 2.3 Analytical Framework Used for Assessing Quality Argumentation | 50 |
| Table 2.4 The five Stages of CAT as proposed by Ogunniyi | 53 |
| Table 3.1 Frequency of demographic Characteristics of the sample | 77 |
| Table 3.2 Analytical model of argumentation modified after Downing (2007) | 120 |
| Table 3.3 The five Stages of CAT modified after Ogunniyi (2007a & b) | 121 |
| Table 4.1 Pre-service teachers' performances on PSAT at observations (O1 - O4) | 132 |
| Table 4.2 Distribution of pre-service teachers' levels of arguments gauged by DAM | 161 |
| Table 4.3 Distribution of pre-service teachers' levels of arguments gauged by CAT | 161 |
| Table 4.4 Good demonstration of problem-solving strategy using nature of arguments | 173 |
| Table 4.5 How did pre-service teachers perform at different observations (O1-O4) | 175 |
| Table 4.6 Indicators for the prediction of pre-service teachers' self-efficacy | 181 |
| Table 4.7 Categories and typical pre-service teachers' responses | 194 |

LIST OF FIGURES

| | | |
|-------------|--|-----|
| Figure 1.1 | Proportions of core and elective subjects for the first year pre-service teachers. | 18 |
| Figure 2.1 | Toulmin's Pattern of Argumentation, (After Erduran et al., 2004) | 47 |
| Figure 2.2 | Diagrammatic representation of a modified self-efficacy | 70 |
| Figure 3.1 | Ethnic group of research participants | 79 |
| Figure 3.2 | Four phase design | 80 |
| Figure 3.3 | Pedagogical scheme for implementing DAIM . | 90 |
| Figure 3.4 | Diagram of a toy train engine P connected to wagon Q | 97 |
| Figure 3.5a | Free-body diagram of toy train engine P | 100 |
| Figure 3.5b | FBD of toy train engine P | 100 |
| Figure 3.6 | Free-body diagram of P and Q | 101 |
| Figure 3.7a | Free-body diagram of wagon Q | 101 |
| Figure 3.7b | FBD of wagon Q | 101 |
| Figure 3.8 | Free-body diagram for (F_{c_y} and F_{c_x}) components of P | 103 |
| Figure 4.1 | Pre-service teachers' observations (O1 and O2) on 12 PSAT items | 127 |
| Figure 4.2 | Pre-service teachers' observations (O3 and O4) on 12 PSAT items | 131 |
| Figure 4.3 | Physical representation of the problems (FBD) by PT15 | 143 |
| Figure 4.4 | Pre-service teacher PT15's math-in-physics problem-solving | 143 |
| Figure 4.5 | Free-body diagram of item 3.6.2 | 145 |
| Figure 4.6 | PT28's approach to math-in-physics problem-solving | 148 |
| Figure 4.7 | PT1's approach to math-in-physics problem-solving | 149 |
| Figure 4.8 | Animation of debate and discussion in a DAIM setting for the study | 154 |
| Figure 4.9 | An object is hard to push because it is heavy | 157 |
| Figure 4.10 | Pre-service teacher (PT39's) math-in-physics problem-solving | 172 |
| Figure 4.11 | Frequency polygon of gain scores of pre-service teachers' ability | 177 |
| Figure 4.12 | Diverging Stacked bar charts for Likert Scale of the present study | 178 |
| Figure 4.13 | Pulling the lawnmower | 188 |
| Figure 4.14 | Pushing the lawnmower | 188 |
| Figure 4.15 | Group C's use of arguments | 198 |
| Figure 4.16 | Arguments diagram drawn by PT10, group F | 201 |

Preamble

Scientific Conceptions That Mock Reality- Argumentation as Coming-To-Knowing

Throughout history we have drawn our conception of sciences and our place in the universe from the current physical theory of the day. To some extent we owe such inspiration to Newtonian physical theory. In terms of how we relate to the world and to other people, the Newtonian influences runs deep. It is still the physics that drives dynamos and puts men on the moon, yet ironically, it is no longer at the forefront of creative physical thinking. The Newtonian categories of space, time, matter, and causality are so deeply ingrained in our whole perception of reality that they colour every aspect of the way that we think about life, and we can't easily imagine a world that mocks their reality.

On the one hand, whenever we drive a car from point A to point B , we are to some extent conscious of the space between the two points and the time it takes to travel between them. On the other hand, opening and closing of a door reminds us of the cause-and-effect relation between the material being of both the door and our hand. How, then, do we deal with a CLAIM that there is no space between separate objects, indeed that there are no objects such as we normally think of them and that the whole notion of "space" or "separate" has no foundation in reality? How do we as physics educators talk about events or relational concepts to our learners if we must give up all conceptions of time and never say that one thing causes another to happen? Such lessons, when first presented, would create a fertile ground for argumentation with certain degree of intellectual numbness for both the educator and the learners. It may in turn, be seen by learners especially non-Western science (African) students as bizarre as it would seem to a layman on the street. Nonetheless, the desire of this study to capture deep thoughts of pre-service teachers as they explore their learning of classic physics through argumentation has necessitated the inclusion of several Newtonian conceptual problems in the research instruments (PSAT).

I feel the radical newness of all manner of responses from the research participants of this study will be apparent as we look at how they use the nature of arguments, Dialogical Argumentation Instructional Model (DAIM) to solve mathematical problems in basic mechanics. Hopefully, I shall avoid the usual trap of trying to fit square pegs into round holes. Thus, despite, the dominance of the Newtonian notion in our lives and thoughts; any excitement about Newtonian physics itself has long gone by. In its stead we have Einstein's relativity theory and quantum mechanics, both of which have changed radically the way

that physics is done. Even so, relativity theory itself is not likely to lead to a new world view. This is because in certain types of historical and anthropological thinking, relativity theory is about the physics of high velocities and very great distances. In this sense, it plays itself out on a cosmological scale and has virtually no application in our everyday life.

In some important ways, while some schoolchildren know that space is curved and time as we know it is a mere illusion, it is very unlikely that ordinary people will find their understanding of daily reality very much coloured by Einstein's work. This is because relativity constructs is doubtless difficult of access to anyone inexperienced in mathematics. I do not mean to imply that relativity theory has no value at present. Far from it. In the first place, Einstein once said of his own theory of relativity that it will have to yield to another one, for reasons which at present we do not yet surmise. It is not difficult to understand why, in spite of this, many physicists, beginning with Einstein, had tried and failed to fuse quantum mechanics and general relativity into a single, seamless unified theory.

Throughout the course of this study I shall be drawing on a great many ways in which argumentation as a coming-to-knowing provide us with a radically new understanding of various aspects of scientific conceptions (e.g. basic mechanics) held by pre-service science teachers studying Newtonian concepts. It is hoped that this study will contribute to the body of knowledge in the area of its intent and through a wedding of physics and mathematics we, too, can have a reconciled viewpoint about the use of argumentation in training our students on problem-solving.

CHAPTER ONE

Prologue

One morning, I walked into my classroom, and found two of my students Simphiwe and Sifundo (pseudonyms) discussing the prospects of the forthcoming South African Soccer league (PSL) just a night after teams had been drawn up. I heard Simphiwe saying, "I'm ready to bet this year: My team, Orlando Pirates, Buccaneers Boys are a certainty for the PSL trophy." His friend Sifundo, a Kaizer Chiefs fan raised his eyebrows: "Why do you say that?" "Simphiwe replied, "Look at Buccaneers' strength! They're solid. Throughout the past two PSL seasons they are defensive and offensive." Simphiwe persisted: "Ah, consider last night's draw - look at the team line-ups against Buccaneers. Kaizer Chiefs have crumbled in the last two seasons and Supersport United are brittle on the defense. They will start with a flourish, but crack under pressure. Ajax of Cape Town are strong on defense, but they just don't have the heavy artillery. Take away their two top strikers, and where are they? I just don't see anyone who can touch the Buccaneers boys. Quietly, Sifundo replied: "Yeah, I get the argument, but I'm just not sure you can afford to rely on past performance that much."

By considering the successive steps followed in this conversation, we can see that Simphiwe begins by claiming that his team, Orlando Pirates (Buccaneers Boys), is such a certainty for the Season's PSL trophy that he plans to bet on their success. In reply his opponent Sifundo, sets about probing the foundations of that claim by asking: "Why do you say that?" This question compels Simphiwe to bring to light other associated data, beliefs, evidence to justify his confident claim. At the end of the conversation, Simphiwe and Sifundo part ways with their differences of opinion unresolved. But they can now understand more clearly what those disagreements rest on, for instance, Simphiwe's assessment of the strengths and weaknesses of his team's opponents, Keizer Chiefs, Supersport United and Ajax of Cape Town shows that his degree of confidence is based on the past performances of these teams and of his team, hence his claim. However, the extent to which one can use past performance to predict the future performance of a soccer team is what Sifundo got his friend Simphiwe to think about. To this end, the conversation between the two students was purely argumentative. Along the same lines of thought, this study is underpinned by an argumentation framework. If one thinks of learning science as tantamount to memorizing science "facts," or as an accretionary building of elaborate sets of behaviours, then much of what follows will be irrelevant. If, however, one accepts the fact that science is built on argumentation (Erduran, Simon, & Osborne, 2004) and that the aim of science education is to promote scientific thinking and reasoning among students, then this study will be of interest.

1.0 Positioning Myself as a Researcher

Most teachers probably encounter difficulties of some or other kind in the teaching of physics. An overriding difficulty, and therefore one that can lead to the greatest excellence if confronted and resolved, is divorcing mathematics from physics. Some of the difficulties peculiar to physics that students may encounter are self-inflicted; others stem from specific features of the

discipline. However, what serves to orientate the focus on these difficulties is the specific close association physics has with mathematics.

Thus there is nothing special about the number of difficulties that confront us in physics, only in the discernible features of each difficulty. And each difficulty we consider gives us a chance to achieve excellence in our teaching if we face it positively. It may be that the bigger the problem, the greater the excellence achieved by its resolution. It seems clear that by grappling with our difficulties and struggling to resolve them we keep our subject alive and our teaching in line with contemporary needs and attitudes.

My experience in teaching mechanics to first year pre-service teachers in one of the historically Black universities in Cape Town, South Africa has provided me with the unique opportunity to encounter real difficulties and therefore has presented a splendid challenge. This challenge compelled me to explore various instructional strategies before finally settling for a dialogical argumentation instructional model (DAIM) which has been increasingly used in circumstances similar to mine. I was aware that most of the pre-service science teachers I taught were intolerant of mathematics as their choice of subject electives in combination with natural science or physics are usually mathematical literacy or other subjects as shown in Figure 1.1 and Table 1.1 respectively.

While I considered my task as an educator of pre-service teachers involved respecting my students' choices I remained well aware of the critical place of mathematics in the study of mechanics. I was equally aware that if my pre-service teachers had opted for mathematics and physics at the lower levels then my problem should be minimal; otherwise it meant the implementation of compatible remedial instructional strategies which would ameliorate their cognitive deficits relative to mathematics. It was this scenario which led me to the idea of exploring the key role of mathematics in physics mechanics, which here forms the central concern of this study.

Mathematics in physics mechanics for the first year pre-service teachers entails the kind of mathematics that provides the essential scaffolding of physics mechanics. This requires an

understanding of matrices and vectors in two dimensions, and the ability to use very simple trigonometric equations to compute complex problems. Also, a deductive technique is needed to integrate various levels of algorithms that lead to solutions. Everything else can be expressed in semiotics and a concept of boundary conditions for a given problem. So basically a student needs to be acquainted with complex numbers so that he/she can understand the significance of solution(s) when he/she obtains them.

Given the troubling issues that my students grapple with in solving mathematical problems in physics, I began looking for an appropriate instructional approach that fundamentally supports problem-solving in small group settings. In particular, I sought an instructional approach that may instill mathematics skills in students who struggle to solve problems. In a more recent attempt to trace the roots of my students' math-in-physics impediment, I came across some teaching and learning scaffolds that appeal within a constructivist paradigm due to their adaptability to the epistemic imperatives within the teaching and learning of the science.

While preparing to explore this matter, I became aware of new instructional strategies to be used as scaffolds to mitigate the challenges faced by my students in mobilizing mathematical concepts to solve problems in mechanics. I derived critical insight from my Masters Study which involved the Science and Indigenous Knowledge Systems Project (SIKSP) and was based on two argumentation instructional frameworks namely, Toulmin's (1958/2003) Argumentation Pattern (TAP) and Ogunniyi's (2004, 2007a & b) Contiguity Argumentation Theory (CAT). I also drew inspiration from Downing's (2007) Analytical Model (DAM).

My participation in SIKSP which involved the use of the dialogical argumentation instructional model (DAIM), eventually became the springboard for the present study. DAIM provided ample opportunities for teachers and learners to co-construct knowledge through arguments, discussions and dialogues. In a DAIM-based lesson learners are able to express their views freely and to air their doubts (Erduran et. al, 2004). Having obtained the necessary impetus from SIKPS and other projects I then trial-tested my newly acquired instructional skills in real classroom situations. However, to put my research journey in proper perspective it is apposite to present a brief overview of how my experience has culminated in the present study.

My first classroom encounter with argumentation was in 2008 at the Cape Peninsula University of Technology (CPUT) in the Western Cape Province of South Africa. Here a group of lecturers were working on a project focused on the development of argumentation skills among science teachers, mostly student teachers enrolled for a continuous professional development programme. This is how I came to be exposed to various elements of argumentation pattern.

Even though the argumentation protocols were exciting, I did not fully understand the Toulmin Argumentation Pattern TAP at the time. After a short period of training small groups were assigned a debatable science topic. The objective was to discuss and provide epistemological aspects of scientific inquiry using the elements of argumentation. The following year I participated in the SKIPS workshops at the University of the Western Cape (UWC), in the School of Science and Mathematics where Professor Ogunniyi presented a paper on enriched argumentation, in his Contiguity Argumentation Theory (CAT).

As a consequence, a symposium about argumentation was organized. It was attended by Masters students, doctoral students and various scholars who coordinated the SKIPS project. From this time I have been developing my interest in argumentation studies, with a focus on science education. This interest has increased at a rapid pace, through my exploration of a wealth of research papers by Professor Ogunniyi, on the subject of argumentation.

My intention in this study is to provide an account of how I have used argumentation instruction to facilitate pre-service teachers' ability to mobilize mathematical concepts in solving problems in mechanics. An account of the CPUT team's research findings provided important information about the nature of interaction in small group discussions. Using the TAP model, the CPUT team observed a unique form of engagement among teachers, which they termed inclusive argumentation (Scholtz, Braund, Hodges, Koopman, & Lubben, 2008). It was also found that practising teachers involved in a development programme in which argumentation was used as one of the teaching strategies, engaged in a unique style of argumentation which precluded rebuttals. The former and the latter formed part of my motivation for this study. In this study, I will focus on the physics content of physical science and will use physics education as a discipline of interest. More details on this will be presented later.

1.1 Introduction

In a science fiction movie, Yoda once said while teaching the young Luke Skywalker that: “You must unlearn what you have learned”. As much as it is a science fiction movie, this also makes sense in the real world, especially when learning physics. Unlike every other science field, physics is different in the sense that students tend to have their own ideas about it even before they learn it in the classroom. For example, we know that everything that moves will eventually come to a stop; that gravity prevents us from flying and that things can be moved if we push them hard enough. The problem is, some of these ideas are not scientifically valid. In the same vein, in most Nigerian Nollywood traditional movies whenever argument ensues over a sacrilegious act, the movie can never reach ‘the end’ without one of the elders in the movie issuing a cautionary statement such as: “Whatever goes up must surely come down.” This is considered to be a powerful statement due to the manner in which it is usually uttered.

Often one hears a declarative statement like the one in the foregoing paragraph in our everyday life, especially during social interactions with others. Unfortunately many who utter such a notion are sometimes ignorant of the underpinning principle(s) and the extent/context of its application. Very often they do so at the expense of justifying commonsensical claims or mere assumptions; they wish to apply a common belief to a matter at stake. So often we hear about this notion. We use it and many others in dialogues, and we use them to complement our arguments and daily construction of knowledge. So to some extent they form and dominate our worldview. I am not implying that such anecdotes are necessarily wrong in all contexts. In fact, human experience does confirm their truism in some sense but scientifically speaking, they are not valid considering that science by nature is anti-intuitive.

What is scientifically valid may not always be considered culturally valid. Hence, in pursuing a study on argumentation with non-Western science students (that is, African students), it is wise to be aware of the difficulties the researcher may encounter along the way. For example, Western education predisposes us to think of knowledge in terms of factual information, information that can be structured and passed on through books, lectures, and programmed courses. Within the western worldview, knowledge is seen as something that can be acquired and accumulated, rather like stocks and bonds. Western minds desire to sort things out, to arrange knowledge in a

logical fashion and order the world into categories. Today, many people have begun to question the more materialistic aspects of this worldview.

By contrast, within the African indigenous worldview the act of coming to know something involves a personal transformation. In this sense, indigenous science can never be reduced to a catalogue of facts in that it is a dynamic and living process, an aspect of the ever-changing process of nature. No matter what our colour, religion, social status or racial origins may be, those of us who have grown up within the African culture might agree that for a long time our culture has been ignored, dismissed, and laughed at. In a similar way, our beliefs have been called superstitions and we have been referred to as primitive people.

In most African schools our children are never taught about their own indigenous science, and for them the only truth about the world is that which is given by western science. The same thing applies, I believe, to cultures that lie outside our own. One can no more understand them from the outside than one can describe the taste of *Egusi soup* to someone who has never eaten such a Nigerian traditional dish. Although we may begin to acknowledge the importance of other cultures, 'races', and worldviews, African education is still, to a great extent, based upon the traditions of Western civilization, that stream of culture that began with the Greeks and Romans and underwent a partial transformation with the rise of science and technology. It is in such a spirit, and with such an aim, that this study presents itself.

This study is not about indigenous knowledge; rather it is concerned with scaffolding argumentation for non-Western (African) science students. It sets out to discover and document ways in which non-Western science students holding different world views can begin to have dialogues that offer them respect and courtesy that is the hallmark of humanity. In this regard, if TWO systems of thought emerge from students' responses, both of which claim to be scientific, such responses will be treated side by side. The desire to compare, to measure, and to categorize in terms of replacing one with the other or determining which is better or worse is not the central concern of the current study. It is at this point that a tantalizing paradox presents itself.

I believe that meaningful learning can come from dialogues between worlds. Thus for the research participants it may be that of coming-to-knowing between worlds. It is my hope that, at its deepest level, a study of this kind would have engendered an increasing flexibility in the students' consciousness, unleashing an ability to leave the boundaries between worlds of learners' worldviews and putative science notions. But how is such a dialogue with non-Western science students to commence? Searching for answers to a question like this, one begins to wonder if it is the right question to ask in the first place, indeed, if such a question makes any sense at all.

To me, the realization comes that it is not so much the question itself that is the problem, but the whole persistent desire to obtain knowledge through a particular analytical route in response to such question. Such a question will metamorphose into another, and so may lead us into a profoundly different reality from that which we encounter in our everyday science life orchestrated by Western sciences.

That being said, this study is intended, as far as possible, to provide an insight into the framework of argumentation for those who, from a homological and dialogical point of view, are interested in the students' dialogical arguments, but who may or may not be conversant with pre-service teachers' use of the nature of dialogical arguments to solve math-in-physics problems.

In order to attain the greatest possible clarity, the study focuses on an analysis of pre-service teachers' ability to use a dialogical argumentation instructional model in order to solve mathematical problems in physics.

1.2 Curriculum reform in South African Basic Education: Tracking Changes

In post-apartheid South Africa where there has been a concerted effort towards increasing the number of black scientists, engineers and technologists, it is undoubtedly teachers have a great role to play towards achieving these demands. In this regard, it is important that we think about what kind of future generation of teachers universities are currently producing; otherwise the delivery of the current curriculum mandates such as CAPS for physical science Grades 10-12

may not be fully actualised. From a didactic viewpoint, it is equally important that we rethink what is being taught and how it is being taught.

At present the prominence given to dialogues, argumentations, discussions and group activities in the South African curriculum C2005 stands out in sharp contrast to the use of a traditional instructional approach and the rote learning associated with the old curriculum (Ogunniyi, 2007a). The National Curriculum Statement (NCS) provides the disciplinary content of the National Senior Certificate (NSC) qualification. Recently, the NCS has been reviewed and replaced by the Curriculum and Assessment Policy Statements (CAPS), which is a streamlined version of the NCS.

Accordingly, the CAPS have been implemented in Grades R-3 and Grade 10 in 2012. In the year that followed it was implemented in Grades 4-6 and Grade 11. And in 2014, it was implemented in Grades 7-9 and Grade 12. The implementation of the CAPS in Grades 10-12 has been hailed as having been beneficial to both teachers and learners in that it clearly indicates the scope and depth of the content to be covered, the assessment requirements as well as the pacing of the content areas per quarter (DoE, 2014, p.18). Also, Curriculum and Assessment Policy Statements – CAPS (DoBE, 2011) – propose ‘critical thinking’ as one of the goals. This is a goal that can be highly beneficial to both teachers and learners when they identify, evaluate and craft scientific arguments. Since it is an aim of CAPS that both teachers and learners be conversant with how to evaluate scientific arguments, it follows that pre-service teachers (those participating in the present study included) have to be trained in argumentation processes so as to develop the skills to nurture argumentation in science classes.

Various studies have shown that interactive classroom arguments and dialogues have tended to encourage teachers and students to externalize their viewpoints on any subject matter (Erduran & Jime’nez-Aleixandre, 2008; Kuhn, 2010). Effective instruction encourages an atmosphere where ideas are raised and contradicted by evidence and by the arguments of others (Dega, Kriek, & Mogese, 2013b; Lawson, 2004).

It can be assumed therefore that the attainment of the curriculum objectives is fundamental and that it requires strategic innovation and training to achieve the set goals. Implementation of the CAPS has been reported to have had a marginal impact on learners' performance in that the system of basic education is said to be on the right path as it moves towards higher standards and improved quality. Despite this sense of relief from a deluge of criticism against the Department of Education (DoE), not much change has occurred relative to the significant drop of grade 12 physical science candidates between 2009 and 2014. For example, in this period, the number of physical science candidates sitting for the matric examination has decreased from 220882 to 103 348 (DoE, 2014, p.74). This decline (117 534) in the number of grade 12 candidates sitting for physical science in the last six years has raised more concerns amongst stakeholders throughout the country.

1.3 Synopsis of South African physical science curriculum for Grades 10-12

In the former version of physical science curricula (NCS-2005), literacy was a major concern. At the same time in the high school Grades 10-12 physical science curricula, the literacy concern was in most cases more weakly expressed. The NCS has a traditional academic form. It means that the curriculum functions as a subject preparing students for higher education in sciences (and technology) careers.

In the latest South African basic education curriculum (CAPS- 2011), the main focus is on understanding the nature of science, technology and phenomena in everyday life. Among the skills which students are meant to have with them after studying physical science at high school is to be able to read, to understand scientific phenomena, to develop critical thinking skills, to develop scientific reasoning, problem-solving skills and strategic abilities. The CAPS for Grades 10-12 physical science puts strong emphases on mathematical thinking and the structure of mathematics as essential elements to the teaching and learning of science.

While scientific and mathematics literacy is important for those who would not pursue higher studies in these subjects, it creates difficulties for those who would like to major in these subjects. For instance, geometry and trigonometry are completely missing in the new curricula, yet these subjects facilitate the development of logical reasoning critical to solving problems in

mechanics. The most difficult thing for some of these students– in my experience of teaching them at first year level – is to ask them to provide justifiable arguments related to any solutions they obtained in math-in-physics problem solving.

1.4 Teaching, learning and assessment of physical science education at the institution under study

In South Africa physical science comprises the study of physics and chemistry. Thus, at high school level (Grades 10-12), physics is treated as paper 1 while chemistry forms paper 2 in terms of assessment protocols. At both universities and colleges physical science is treated as a different entity, depending on the career path. It also forms part of the admission entry requirement into universities, colleges or any other institutions for those pursuing science, engineering and technology careers.

For most education and social sciences faculties in the country, especially the faculty in which the present study was conducted, teaching, learning and assessment of physics and chemistry are graded. For example, first year physical science education students do chemistry 1 and physics 1. And those in second year do chemistry 2 and physics 2 sequentially as they progress. Thus the teaching of chemistry 1 and physics 1 is synchronized on a semester basis.

Usually physics and chemistry are sequenced as follows: students who register for physical science 1 will be taught physics 1 in the first semester and the chemistry 1 in the second semester. Chemistry 1 thus forms part of the completion of physical science 1. Each semester consists of at least a five-month period of tuition. At the end of the academic year the chemistry 1 and physics 1 marks are combined and treated as the assessment of physical science 1. The problem with the teaching and learning of physical science at the institution is that little time is spent on the subject matter in preparing these pre-service teachers. It is a concern that the method (in terms of teaching of physics) at the institution is exactly the same as it is at high school where learners spend half of the year doing physics and the remaining half on chemistry. This raises questions as to the readiness of these pre-service teachers and the degree to which they are equipped– in terms of content knowledge readiness – to deliver the new curriculum mandate when they join the teaching profession.

1.5 Challenges facing school science and mathematics in South Africa

According to Nongxa (2010), South Africa has the best developed and most well-resourced system of education and training on the African continent, with the largest proportion of GDP going to education. In the light of this the country is under pressure to keep abreast of scientific and technological development. Consequently science teachers have a considerable responsibility since it is at school level that basic scientific skills and processes are learned. At present, one of the major challenges facing school science and mathematics in South Africa is the declining percentages in passes and poor pass averages. This situation is even more pronounced in historically disadvantaged schools.

Nongxa (2010) notes that many adult South Africans are functionally illiterate and many children are learning in school conditions which resemble those in the most impoverished states. Teacher talk and learner passivity still hold sway in the science classroom. And teachers rely heavily on textbook notes and practical instructions.

As a way of addressing these troubling issues in the teaching and learning of sciences and mathematics in South Africa, a very particular didactic approach has to be adopted. There is a need for the consistent application of good teaching methods that complement the mandate of the new curriculum document, CAPS. This process may be facilitated by the new curriculum which is based on a learner-centered approach in a cooperative learning environment.

In the process of modifying the new curriculum, many institutions of higher learning have modified their own instructional approach for pre-service teachers. Many teacher training institutions have embarked on searching for instructional approaches that would match the mandates of the new curriculum. This entails equipping pre-service teachers with didactic techniques that would enhance meaningful learning.

One such initiative is the research-based instructional strategy aimed at developing science teachers' teaching and learning methodologies at the University of the Western Cape. It is based on a dialogical argumentation instructional model (DAIM) as espoused by Ogunniyi (2004,

2007a & b). This teaching method which has already been used by many science teachers, has gained a fair degree of success (see Diwu & Ogunniyi, 2012; Ramogoro & Ogunniyi, 2010).

The challenge therefore is to attempt, through the use of DAIM, to analyze pre-service teachers' ability to solve mathematical problems in physics. It is also necessary to note the reference to other attempts in which argumentation was used; both as an instructional approach to teaching science problem-solving to students at different levels of learning, and as a way of promoting meaningful learning (See for example, Berland & Hammer, 2012a; Jones, 2013; Russ, Lee & Sherin, 2012). Likewise, some of the conventionally trained science educators at higher educational institutions have relied heavily on dialogical argumentation as an instructional strategy in their teaching of science (Diwu & Ogunniyi, 2012; Ogunniyi, 2004, 2007a & b, 2009).

There is thus consensus among science educators from various institutions that participants in their studies have benefited from argumentation scaffolding. This argumentation process has increased their critical reasoning and so enabled them to comprehend science as a way of knowing and behaving (Berland & Hammer, 2012b; Lubben et al., 2010; Ramogoro & Ogunniyi, 2010). Such critical reasoning has endowed them with thinking skills that are acquired largely through practice.

Researchers have over time, analyzed the ways in which students blend conceptual and formal mathematical reasoning in solving physics problems (Kuo, Hull, Gupta, & Elby, 2013). Now the implication for science education is that unless this form of thinking is explicitly taught, modelled and supported in the classroom, learners are unlikely to acquire it (Simon, Erduran, & Osborne, 2006).

1.6 Rationale for the study

The rationale for this study may be found in answer to the question: 'Why is it necessary to research the process by which pre-service science teachers come to develop the ability to use the dialogical argumentation instructional model (DAIM) to solve mathematical problems in physics?'

In answer to this question then, a need for this study arose from the main findings of my Master's study. In that study I investigated pre-service science teachers' conceptual and procedural difficulties in solving mathematical problems in physics. The study was conducted in one of the historically black universities in the Western Cape. Some of the findings suggested that the pre-service teachers involved in the study could not overcome conceptual and procedural difficulties after solving multiple physics mechanics problems. Many of them provided solutions that contained invalid mathematical operations contrary to the algorithms steps taught. Their responses to items of the achievement test were indicative of a poor understanding of mathematical concepts required to solve physics problems. They were not able to interpret, argue, analyze or solve given problems correctly (Iwuanyanwu & Govender, 2016).

Nearly 57% of the focus group in the study seemed to subscribe to algebraic formalism with little or no qualitative understanding of the concept in question. Pieces of evidence extracted from their procedural steps leading to solutions, and related findings from the instructional literature suggest that such pre-service teachers may have manipulated symbols to obtain numerical answers, but most probably lacked a clear understanding of the problem situation. This was also evident in the way they constructed and justified their solutions to given problems. In the same vein, they could not provide or use justifiable arguments in their reasoning while solving given mathematical problems in physics. These concerns provided the motivation for further study of the kind of investigation that may be required, as well as an analysis of students' ability to use a dialogical argumentation instructional model to solve mathematical problems in physics.

1.7 Research purpose

The purpose of this study is to explore the nature of argumentation that pre-service science teachers use to solve selected mathematical problems in physics. The study attempts to: (1) identify the nature of argumentation strategies used by pre-service science teachers to solve mathematical problems in physics; and (2) to determine the effectiveness of a dialogical argumentation instructional model (DAIM) on their ability and sense of self-efficacy to solve mathematical problems in physics. Put simply, I want to know how the pre-service science teachers construct, interpret, analyze, and use justifiable arguments in their reasoning that lead to solutions to given problems in mechanics.

It is hoped that findings from the study may provide additional insight about the efficacy of an argumentation instruction such as the DAIM in enhancing pre-service teachers' ability to teach mathematical problems in physics to their students when they have qualified. In a best case scenario, it is expected that by going beyond the usual boundaries of the tools of argumentation teaching and learning, they will also be able to implement the dialogical argumentation instructional model, DAIM. Here I refer to the one underpinned by Toulmin's (1958/2003) argumentation pattern (PAT) and Ogunniyi's (2004, 2007a & b) contiguity argumentation theory (CAT) in teaching problem-solving in physics where the use of mathematical concepts is required. It is also hoped that insights arising from the study will prove useful and informative in programmes aimed at equipping pre-service physical science teachers, particularly those who may later teach Grades 10-12. In pursuance of this aim answers were sought to the following questions:

1. What types of argumentation strategies did the pre-service science teachers use in solving mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM)?
2. How effective was DAIM in enhancing the pre-service science teachers' ability and sense of self-efficacy to solve mathematical problems in physics?

1.8 Problem statement

Over the past years, teachers' competence to teach Grades 10-12 physical science in South Africa has come under much scrutiny. Numerous concerns have been documented.

One study was conducted by Basson and Kriek (2012) in three provinces of South Africa namely, Gauteng, North West and Western Cape. A total of 68 FET physical science teachers from urban, township and rural schools participated in this study entitled "*Are Grades 10-12 physical science teachers equipped to teach physics?*" Basson and Kriek's interesting question alerts us to the diminishing competence of physics teachers. One of their main findings reveals that teachers' lack of subject content knowledge especially in township and rural schools, cannot be blamed on curriculum modification. The findings further reveal that most teachers tested could not perform simple conversions or implement contextual knowledge.

Given these troubling issues the authors argue that teachers, who do not fully understand the content they teach, equally might be unable to detect right or wrong answers in the textbook calculations they use. The question of what this means for learners in the care of these teachers is a concern that cannot be negated or ignored. In a cameo of what might be the causes of these perpetuating issues Selvaratnam (2011) states that there are multiple, complex problems that contribute to South African students' poor performance. These include teachers' poor content and pedagogical knowledge, infrastructure of schools and low teacher qualifications. The concern that one problem will always lead to another is a warning to the kind of future generations of science students that such teachers – who themselves struggle to solve mathematical problems in physics – will produce.

Other recent studies in South Africa have shown reiterations of these concerns. In these studies different research strategies have been used to explore pre-service teachers' cognitive engagement within the field of mathematics and science education. For example, Govender and Dega (2016) studied third year pre-service teachers' conception of vector-kinematics. Like the present study, which implicates the teaching and learning of basic mechanics, they found that pre-service teachers displayed a lack of higher level conceptual understanding of vector-kinematics. Part of the etiology of these conceptualizations of the use of mathematics in physics may be attributed to the complexity in deciphering the interrelatedness of their nature. In the light of this point, it may be accurate to say that mathematical knowledge in physics is determined not only by the circumstances in which it becomes a deductively structured theory, but also by the procedures that originally led to or may lead to it. That is to say, the process of producing mathematical knowledge needed to solve physics problems is equally important especially from a didactical point of view, hence the pursuit of the current study.

1.8.1 Concern that one problem may lead to another: Mathematics education an elective for physical science pre-service teachers

Course guidelines at the university where the present study was conducted imply that mathematics is optional to pre-service science teachers of the Further Education and Training (FET) level. Thus for throughout their studies these students are entitled to choose any subject combination of the electives on offer. First year FET pre-service science teachers are expected

to do seven compulsory subjects and a minimum of 2 or maximum of 3 elective subjects known as majors as shown in Table 1.1.

Table 1.1 Proportions of core and elective subjects in each year of Further Education and Training (FET) program at the institution understudy.

| | Core subjects (Compulsory) | Elected Subjects | E.g. Specialization | Free Choice |
|------|---|--|--|--|
| YR 4 | Education 4 Education Practice 4 General Theory Professional Studies 4 <i>(ALL FOUR compulsory subjects are tools for 6 months internship at schools- leading to completion of 4th year)</i> | NO ELECTIVES | Curriculum Studies for specialised electives (e.g. Physical science 4, Mathematical literacy 4) <i>(No teaching of subject Content for pre-service teachers at this exit level)</i> | NO CHANGES ON ELECTIVES |
| YR 3 | Education 3 Professional Studies 3 Teaching Practice 3 Communication in English 3 Skills & Life Orientation 3 <i>(Five compulsory subjects)</i> | <i>Students proceed with the subjects elected in second year</i> | Physical science 3 Mathematical literacy 3 <i>(Teaching of Content)</i> <i>Plus all core compulsory subjects</i> | NO CHANGES ON ELECTIVES |
| YR 2 | <i>Students proceed with ALL the seven compulsory subjects from first year (e.g. Education 1 to Education 2, and so forth)</i> | <i>Students proceed with the subjects elected in first year</i> <i>Conditional elective allowed</i> | Physical science 2 Mathematical literacy 2 <i>(Teaching of Content)</i> <i>Plus all core compulsory subjects</i> | <i>One of the elective subjects from first year may be dropped</i> |

| | | | | |
|------|---|---|--|-----------------------|
| YR 1 | Education 1 Professional Studies 1 Computer Literacy 1 Philosophy of Life & Lifeskills 1 Teaching Practice 1 Communication in English 1 Skills & Life Orientation 1 | Mathematics 1 Physical science 1 Life science 1 Mathematical literacy 1 Technology 1 Entrepreneurship (EMS) 1 Afrikaans 1 Xhosa 1 Computer science 1 Communication in Afrikaans 1 Communication in Xhosa 1 <i>(All elective subjects are offered with their respective curriculum studies)</i> | Physical science 1 Mathematical literacy 1 Afrikaans 1 <i>Plus all core compulsory subjects</i> | NO FREE CHOICE |
|------|---|---|--|-----------------------|

The elective subjects include a wide range of FET band subjects (that is, Grades 10-12 high school subjects). University first year elective subjects include mathematics 1, physical science 1, biology 1 and so on as depicted in Figure 1.1. This means that at first year level a pre-service teacher who wants to specialize in three high school subjects can take mathematics 1, physical science 1 and biology 1 or other combinations. At the second year level a pre-service teacher is allowed to drop any one of the three elective subjects as long as s/he passes it (see Table 1.1). And as such s/he must continue with two other elective subjects as majors (specialization) up to the end of the four year degree program. Again, nothing forbids a pre-service teacher from specializing in three elective subjects as long as the subjects are passed at all levels with a minimum of 50%.

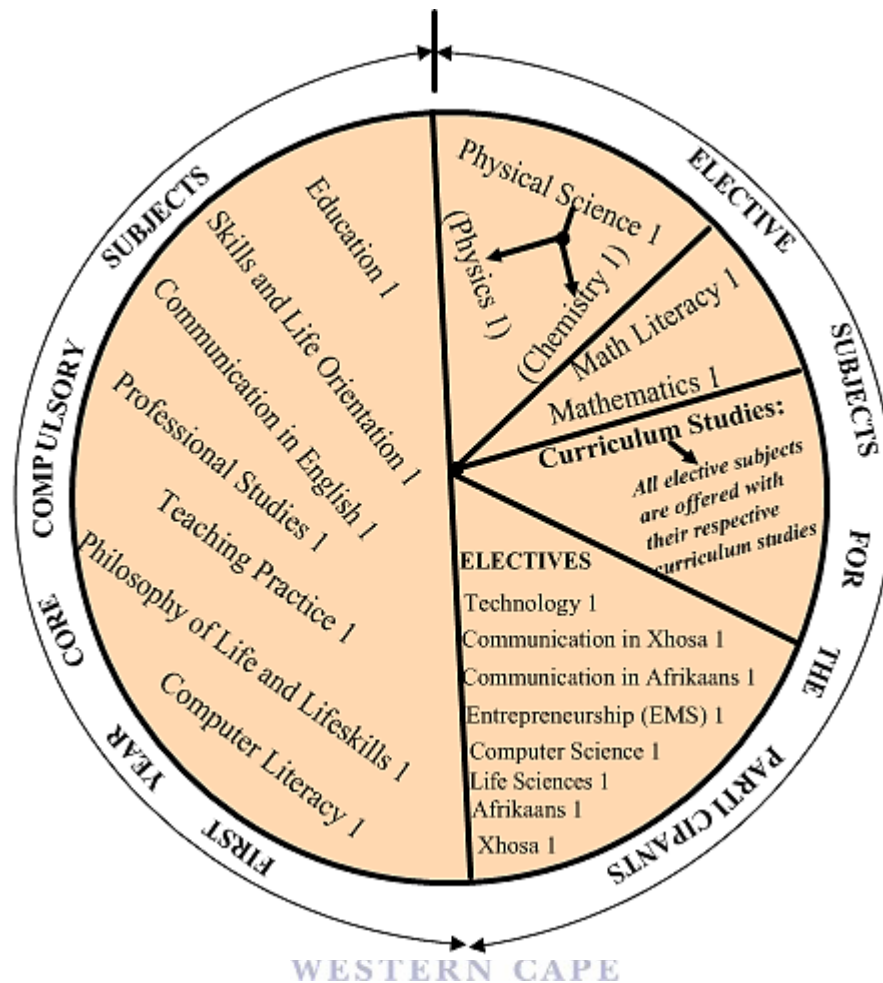


Figure 1.1 Proportions of core and elective subjects for the first year pre-service teachers.

In Figure 1.1 it is clear that pre-service science teachers are not restricted to any subject combination; thus many of them choose to avoid mathematics completely. Some choices of subject combination include physical science and a local language such as Afrikaans or Xhosa. Others choose business subjects with physical science, etcetera. The problem with these combinations multiplies for the following reasons:

- Lecturers have much work to do to retrain students coming fresh from high school who may have not done mathematics up to the level needed to understand physics education.
- A great deal of time is spent on remedial classes for those who grapple with basic mathematics concepts. This time would have been well spent on deepening the motivation of pre-service teachers' learning of science education.

- An unconscious tendency exists on the side of the lecturers to drop or compromise the level of university academic expectation during assessments so as to accommodate this messiness.
- Little time is allocated for the teaching of physics education content in its entirety. Instead such time is further diminished by the necessity to close conceptual gaps for students whose subject electives do not include mathematics, and for those who grapple with conceptual resources when confronted with math-in-physics. This is gravely challenging.

Further to this, several studies have revealed some of the challenges the aforementioned pre-service science teachers may face when they attempt to solve mathematical problems in physics. There is sufficient empirical research evidence to show that a lack of mathematical skills can have a negative impact on teachers' and students' abilities to solve complex problems in physics and can greatly hinder a deeper understanding of many important concepts especially those of a scientific nature (Bing & Redish, 2008, 2012; Gupta & Elby, 2011; Kuo et al., 2013; Redish & Gupta, 2010). It has also been reported that students invent their own mathematics to solve problems in science (Levin, Grant, & Hammer, 2012; Redish & Gupta, 2010; Wilkerson-Jerde & Wilensky, 2011).

Based on these insights, my concerns focus on the elective subjects pre-service teachers often opt for in conjunction with physical science. This concern and those raised earlier may not be adequately answered if one does not take into account the pre-service teachers' mathematics history, for instance, at high school exit (grade 12) level. This is documented in Chapter 3 of the study. Thus a central assumption being investigated in this study concerns pre-service science teachers' urgent need for help to improve their abilities in math-in-physics problems and in the didactic methodological repertoire. The attainment of such an objective may provide them with useful insights and help them to assist the students they will later on teach when they join the teaching profession.

When Nguyen and Meltzer (2003) investigated pre-and-posts tests of students' knowledge of vectors in an introductory mechanics courses they found that over one quarter of the students

completing a calculus-based mechanics course, and one-half of the students completing the algebra-based course were unable to resolve vectors in two dimensions.

What seems needed therefore is an emphasis on the integration of epistemological issues in physics teaching and learning so as to expose its intrinsic mathematical dimension. This would lead to gain a better understanding of specific parts of physics and a deeper awareness of what physics is as a discipline. This is because negating the significance of epistemological issues in the use of mathematics in physics is like trying to isolate “what matters” in describing a physical system – one in which the complex behavior of the system arises from combinations and elaborations of the simple structures and their interactions. This is most important, especially today when there is much concern about the level of physics and mathematics that students are learning and about their decreasing interest in both physics and mathematics at a time when the need is rising for science and technological skills as well as a broader general education.

As a way to address the latter concerns, two theories emerge. Both have been used in many instances: Toulmin’s (1958/2003) Argumentation Pattern (TAP) (Erduran et al., 2004) in conjunction with the Contiguity argumentation theory (CAT) (Diwu & Ogunniyi, 2012; Ogunniyi, 2004, 2007a & b; Ogunniyi & Hewson, 2008; Ramogoro & Ogunniyi, 2010). While TAP is useful for validating claims in the logical induction-deduction arguments characteristic of school science, CAT takes care of both logical and non-logical discourses. For the present study, it is conceivable that CAT can answer the question: 'What types of argumentation strategies did the pre-service science teachers use in solving mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM)?' Additionally, in order to form the theoretical basis for answering this question in the present study, the dialogical argumentation is enriched with the didactic notion of social constructivism. This framework is presented in Chapter 3.

1.9 Significance of the study

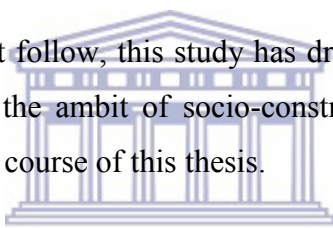
The concerns expressed in the foregoing section show that the pre-service science teachers who participated in this study lacked investigatory or innovative problem-solving skills. This is a serious matter since – as already stated – it is important for teachers to be competent problem

solvers if they are to be able to teach physical science effectively. For pre-service teachers to teach physical science effectively, it is necessary that they be competent in a complex web of knowledge domains: knowledge of and about physical science and about pedagogy of physical science (Ergul, 2013; McDermott, 2008).

As alluded to here, some studies have already been done in this area of intent, both locally and internationally. Nonetheless, repeated challenges are noted among pre-service teachers in problem-solving in math-in-physics (Govender & Dega, 2016; Ndlovu & Brijlall, 2016; Nguyen & Meltzer, 2003). From my point of view there is a need for science teacher training programmes to address this troubling issue.

1.10 Theoretical Framework

As will be seen in the sections that follow, this study has drawn on various theoretical sources, particularly those that fall within the ambit of socio-constructivism. The different theoretical approaches will be presented in the course of this thesis.



1.10.1 Entrance for the present study into Argumentation paradigm

I thought that one way of making a theoretical framework more meaningful to the readers is by taking the readers through the dawning of the theoretical framework. Therefore, I think such discussion of dawn of a particular theoretical framework may conform to brevity sake depending on the nature of the study that one is pursuing. If this counts, then in this episode, I want to understand Toulmin argumentation model and Contiguity Argumentation Theory (Ogunniyi, 2007a & b). In order to explore Toulmin's argumentation model and Contiguity Argumentation Theory (Ogunniyi, 2007a & b), I shall begin by briefly revisiting a description of argument in ancient Greek philosophy.

Aspects of arguments can be found among the works of Socrates, Plato and Aristotle (ranging from 470 to 320 B.C.). Ever since Aristotle it has been customary, when analyzing the microstructure of arguments, to set them out in a very simple manner. There have been three propositions at a time, minor premise; major premise; so conclusion. The question now arises as to whether this standard form is sufficiently elaborate or candid. Simplicity is of course a merit,

but in this case may it not have been bought too dearly. Can we properly classify all the elements in our arguments under the three headings, ‘major premise’, ‘minor premise’ and ‘conclusion’, or are these categories misleadingly few in number? It was Stephen Toulmin who attempted to answer this epistemological question by creating an argument model. This model has come to be known as the ‘Toulmin Argument Pattern’ (TAP). But this model, as shall be explained later in the next chapter, has its own merits and demerits. Surely the model of all argumentation should be at least as complex.

1.10.2 Understanding the Contiguity Argumentation Theory (CAT)

The Contiguity Argumentation Theory (CAT) by Ogunniyi (2007a & b) is increasingly being used by African science educators seeking ways of connecting western science to indigenous knowledge systems. Before CAT became well-known most scholars tended to consider these systems of thought as incompatible. However, since its appearance in the literature more and more scholars have found CAT to be a handy theoretical tool for explaining the logical and non-logical issues that often arise in multicultural classroom discourses. Among the immediate advantages has been the opportunity created through CAT to undertake dialogical argumentation that is culturally relevant, there by facilitating teachers’ and learners’ awareness of their cultural sensitivity and sense of identity.

CAT has also been used as an analytical tool for determining perceptual shifts that tend to occur in an argumentation discourse for example, the shift from a scientifically dominant stance to a traditional stance as the contexts of the arguers change. Furthermore, it has brought to scholars’ awareness the legitimacy of indigenous knowledge as a valid way on interpreting experience.

In recent years argumentation instruction has brought a fresh perspective to bear on the teaching-learning process especially in Africa where the traditional chalk-and-talk approach has dominated classroom discourse for decades. Argumentation theory and discourses as espoused by Ogunniyi's (2007a & b) Contiguity Argumentation Theory (CAT) provide valuable theoretical supports and successful instructional strategies from research for learners who come from indigenous backgrounds. More comprehensive details on Toulmin’s Argument Pattern

(TAP) and Ogunniyi's Contiguity Argumentation Theory (CAT) are presented in Chapter 2. These and other theories will be explored in the next chapter.

1.11 Delimitation of the study

According to Ogunniyi (1992) the delimitation of a study is concerned with the scope or the boundary of the study. In the light of this, this study focuses mainly on a pre-service teacher training program offered at one of the universities in the Western Cape, South Africa. In order to set a clear boundary, this study has looked specifically at first year pre-service science teachers' use of argumentation to solve mathematical problems in physics. Due to time constraints this study excludes the second, third and fourth year pre-service teachers. My masters' studies account for the second and third year students' exclusion from this study.

The fourth year was purposefully not selected for the study due to the constraints outlined here. The study investigates pre-service teachers' ability to use a dialogical argumentation instructional model to solve mathematical problems in physics. This then requires math-in-physics content presentations that fit in with the course guideline of the participating group so that no contact time is wasted. In the education faculty where the study was conducted, the exit level of physics content teaching is at the third level. Viewed thus the faculty of science education (FET) course guideline for the fourth year has no physics content at the fourth year level (see Table 1.1), but didactic content and practices instead. As such, the fourth year pre-service teachers spend the first six months of the year in lectures performing didactic activities such as macro-teaching, completing assignments, learning more about the curriculum that they will later be expected to teach when they join the science teaching fraternity (Grades 10-12 physical science). It is for these reasons that the study limits itself to the first year students taking into account only the level at which the research problem can be investigated fully.

1.12 Overview of the Study

Each chapter of this study has been written with the focus on a pre-service teacher-oriented approach to using the nature of arguments for solving mathematical problems in physics.

1.12.1 Chapter One: Research Problem and setting

Chapter 1 provides the background to this study, the purpose of the study, the questions the study sought to answer and the significance of those questions as well as their answers to the tertiary education system in South Africa.

Thus the study attempts to: (1) identify the nature of argumentation strategies that pre-service science teachers use to solve selected mathematical problems in physics; and (2) to determine the effectiveness of a dialogical argumentation instructional model (DAIM) on their ability and sense of self-efficacy to solve selected mathematical problems in physics.

1.12.2 Chapter Two: Review of related literature

Chapter 2 provides a more detailed review of relevant literature with respect to the meaning and importance of the process of dialogical argumentation as an instructional approach for teaching and learning of tertiary physical science, in particular, physics mechanics 2D motion to first year pre-service teachers. At the forefront of relevant literature are works of Toulmin Argumentation Pattern-TAP, Ogunniyi's Contiguity Argumentation Theory-CAT, Downing's (2007) Analytical Model, Bandura's work on Self-Efficacy, and the works of other authors who deserve acknowledgement. These include (Erduran et al., 2004; Osborne et al., 2006), and others. Chapter 2 also investigates teaching and learning strategies that could be used to overcome or reduce mathematical problems commonly encountered by pre-service teachers in physics mechanics.

1.12.3 Chapter Three: Research design and methodology

Chapter 3 presents the research design, the research processes, the methods used for data collection and analysis, as well as the development of the instruments. The following instruments were used in the course of this research: questionnaire instruments, self-efficacy test (IFDSE), Physical Science Achievement Test (PSAT), classroom observations (GCEA), and semi-structured interviews for qualitative analysis. These interviews serve to corroborate one set of

findings with another in the hope that two or more sets of findings would converge on a single proposition (Massey, 2004, p.2). Steps taken to construct and validate the research instruments used in the study are clearly described and illustrated. In Chapter 3 a detailed explanation of the argumentation-based instructional intervention programme (DAIM) is provided.

1.12.4 Chapter Four: Data presentation, analysis and discussion

Chapter 4 presents analyses of both quantitative and qualitative data emanating from the two key research questions. Thus, the overarching analysis makes use of: argumentation, (CAT, DAM) and self-efficacy together as an investigative framework. The major purpose of this presentation and analysis is to compare several recorded observations (O1-O4) of the pre-service teachers' knowledge and skills. A four-phase design was implemented in the DAIM setting from which data was collected.

The chapter also relates the research findings to the two research questions and to the reviewed literature in order to find areas of congruence and divergence. In general, explanations for both the convergence and the divergence of these findings are offered.

1.12.5 Chapter Five: Conclusion, implications and recommendations

Chapter 5 provides a synopsis of the major findings and their implications for teacher education programmes aimed at training science teachers of Grades 10-12., Chapter 5 also provides recommendations for curriculum policy and education programmes.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

While Chapter One provides a synopsis of the study, its foundation and its rationale, this chapter begins with a description of other studies. The main focus of this chapter is material that is theoretically relevant to my own study.

2.1 Argument and Argumentation skills

2.1.1 Definitions

In this study I use Contiguity Argumentation Theory (CAT) and Toulmin's Argument Pattern (TAP) as a theoretical framework and guide. With others, Evagorou and Osborne (2013), I view argumentation, especially collaborative or dialogic argumentation, as the social construction of knowledge in which the learners are expected to share ideas, question assumptions and restructure their existing knowledge schemata based on the interactions in their groups.

There are two reasons why I introduced CAT. Firstly, CAT is dialectical or dialogical in nature and supports both formal, informal logic and even non-logical or value-laden arguments based on culturally accepted norms often encountered within the indigenous communities where most of the students were reared. And secondly, since my students were to be in small group discussions, it was necessary to have a framework that supports the coordination of different perspectives as well as the social construction of knowledge, in which people collectively discuss and decide on the construction of shared knowledge. In this mode, dialogical argumentation serves as a key skill used to make decisions logically and to solve problems (Driver, Newton, & Osborne, 2000). It requires participants to communicate their viewpoints, to consider assumptions in their personal theories and to rethink their original ideas, based on new information (Schwarz, 2009). Therefore, an emphasis on dialogical argumentation in my study is consistent with the goal of improving students' scientific reasoning and proficiency in advancing, critiquing and justifying claims (Khun & Udell, 2003), and in solving problems (Driver et al., 2000). Recent trends in science educational research have seen words such as

“arguments” and “dialogical,” yet these have grown from an epistemology that has been around a long time.

For example, argument is not a new concept. The meaning of argument in educational literature may be understood in two ways, generally speaking. One definition, according to the Britannica (2008), argument is advancing a reason for or against a proposition or course of action. This kind of argument is common in science lessons in which a teacher comes to a class with a scientific explanation and helps the learners to see it as reasonable. The second interpretation of argument is “dialogical” which is when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action (Driver et al., 1998). I shall now proceed to define argumentation.

According to Kuhn and Udell (2003), argumentation is the process of making a claim and using evidence to justify that claim. So to make a distinction between *argument* and *argumentation* put simply, argument refers to the substance of claims, data, warrants, and backing that contributes to the content of the argument; whereas argumentation refers to the process of assembling these components as espoused by Toulmin (1958/2003). As stated earlier, argument and the argumentative practice are seen as a core activity of scientists and have a central role in science education. To enhance the public understanding of science and to improve scientific literacy, argumentation must be given a high priority in education about science and within science itself (Driver et al., 1998). This begs an important question which I shall proceed to explore.

2.2 Is teaching argumentation skills important for students' learning of science?

In the history of scientific perspectives, science has tended to progress more by argumentation, dialogue, and revolutionary ideas than by consensus (Abd-El-Khalick, 2004; Kuhn, 1970; Popper, 1968, 2001b). Therefore, it is important that students engage in argumentation and develop their argumentation and reasoning skills to understand science better.

A study that merits specific attention here is the one that provides a summary of three different arguments for enhancing argumentation skills (Aufschnaiter, Erduran, Osborne, & Simon, 2007). Their study asserts that: (1) scientists engage in argumentation to develop and improve scientific

knowledge, (2) the public has to use argumentation to engage in scientific debates, and (3) students' learning of science requires argumentation. In this section the third argument is particularly important and will be discussed in more detail.

Research has shown that the teaching of argumentation through the use of appropriate activities and pedagogical strategies can be a means of promoting epistemic, cognitive and social goals as well as enhancing students' conceptual understanding of science (Osborne, Erduran, & Simon, 2004). It is not difficult to understand why the authors hold such view. To make sense of it, it can be stated that the adoption of any new approach that promotes the use of argument would require a shift in the nature of the discourse in science lessons.

What this then means is that science education should not only involve transmitting a set of known facts to students, but should also focus on encouraging students to engage in critical thinking about scientific concepts, to support their claims using evidence, and to justify their ideas with practicable explanations (Berland & Reiser, 2009). This should be seen in relation to providing students with tasks that require discussion and debate and which give an opportunity to teachers to engage students in the construction of arguments through the process of argumentation (Jimenez-Aleixandre, 2002; Simon et al., 2006).

In science classrooms, it is important not only for students to be able to make sense of data to construct claims, but also to be able to consider alternative claims and to critique the claims and justifications provided by their fellow students in the context of dialogic interactions. In addition, there are convincing arguments in the extant literature to the effect that addressing epistemological issues may help to advance conceptual understanding. For example, through the use of texts that include arguments, a refutation of common misconceptions can be achieved (Hynd, Alvermann, & Qian, 1997).

Fortunately, argumentation has become increasingly prevalent as an essential goal for science education. Learners are expected to support claims using appropriate evidence and reasoning, and to critically consider alternative explanations (Duschl, Schweingruber, & Shouse, 2007).

Yet incorporating argumentation into classroom science is challenging and can be a long-term process for both teachers and learners (Osborne et al., 2004).

2.3 Students find it difficult to engage in dialogical Argumentation

Argumentation as an instructional discourse has been studied extensively in the field of science education for nearly two decades and to some extent much has become known about the merits and demerits of the approach. A surplus of studies has shown that argumentation is increasingly viewed as a leading instructional approach and educational goal for science education. Still, students find it difficult to engage in dialogic or collaborative argumentation, either in whole classroom discourse (Erduran et al., 2004), or in group discussions (Sampson & Clark, 2008), unless it is specifically scaffolded for them e.g. structuring the learning environment (Bell, 2004) and the teacher (Berland & Reiser, 2010; McNeill & Pimentel, 2010).

In support of the foregoing studies, Kuhn and Gohn (2005) conducted a study in which students were asked to evaluate the arguments of other students by: 1) identifying key elements of arguments and 2) judging their quality. In this process they were to gauge whether the arguments were reasonable and whether they provided sufficient evidence. Results obtained showed that students were weak in evaluating the epistemological characteristics of arguments or what they understand arguments to mean, due to poor reasoning (Goldstein, Crowell, & Kuhn, 2009). This suggests that students focus on the content of arguments as opposed to their structure and lack reasoning because they judge the arguments of others based on their own preferences and ignore the epistemic strengths or weaknesses of the arguments themselves (Kuhn, 2005).

The author further explained that school science is often portrayed in a “positivist perspective” for instance, the impression is created that science is a subject with clear “right answers” and in this subject data leads to agreed conclusions. When science is introduced to students simply as a process of memorizing facts and concepts, it gives them an inaccurate view of how science is actually practised, and devalues the ideas and thoughts of the individuals receiving the information (Venville & Dawson, 2010; von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

As Simon et al. (2007) would argue, only if argumentation is specifically and explicitly addressed will students have any opportunity to explore its use in science. A particularly important area to scrutinize is the traditional pattern of argument or debate used by teachers in the science classroom as this has contributed to students' difficulties in developing argumentation skills.

Supplementing these ideas, Lemke (1990) argues that traditional patterns of argument or debate in science classrooms place teachers in a position of power in which they control the topic, the direction of the conversation, decisions concerning who participates in the discussion and what contributions count as legitimate. Thus, this type of traditional discourse focuses on conveying the correct answer and on having learners repeat back to teachers the content they had previously learned. In response to this situation, Lehrer and Schauble (2006) asserted that traditional science discourse patterns are not appropriate as the sole discourse pattern in inquiry-oriented classrooms because they are based on teacher-driven instruction and known answers to questions. Such traditional patterns of argumentation could explain or form part of the major cause of students' difficulty in evaluating their peers' arguments, as has been revealed by Kuhn and Gohn (2005).

Related to this, a study was conducted by Richmond and Striley (1996) in an attempt to understand the process by which students solve scientific problems, the difficulties students encounter in developing the requisite pieces of scientific arguments while negotiating their social roles and the ways these roles shape task engagement and the development and articulation of the arguments themselves. The results demonstrated not only that knowledge building involves the construction of scientifically appropriate arguments, but that the extent to which this knowledge building takes place depends on: students learning to use tools of the scientific community. It also depends upon their expectations about the intellectual nature of the tasks, their role in carrying out these tasks and on the access they have to the appropriate social context in which to practise developing skills. Kuhn (2005) proposes that argumentation involves the exercise of both thinking skills and discourse skills. Hence development of it ought to be an important educational goal.

In addition to what these studies have established, one tends to think that some of the difficulties students experience with dialogical argumentation might be due to our tendencies as science

teachers to impose orthodox science on them. By this I mean that scientific concepts are often presented as a set of known facts which students are required to memorize (Cross, Taasoobshirazi, Hendricks, & Hickey, 2008).

Herrenkohl, Palinscar, DeWater and Kawasaki (1999) talk about the “mistake stigma” in science classrooms wherein the objective of schooling is to get the correct answer, and mistakes are viewed as bad. This pattern suggests that the teacher is looking for correct responses only and is the sole knowledge authority in the classroom. Authoritarian classroom interaction in which the teacher focuses the discussion on one meaning or on one point of view most frequently occurs through this pattern (Kelly, 2007). Taken further, science classrooms should include opportunities for students to engage in classroom discussions in which students practise talking science, challenge each other's ideas, and influence the direction of the discourse.

Even though some of the studies reviewed thus far have shown that students find it difficult to engage in dialogical argumentation, research on its effectiveness in the field of education, and in particular on the teaching and learning of science, is generally receiving due priority. An overview of these studies has shown that many students at various academic levels, have difficulty in developing argumentation skills (Kelly, Regev, & Prothero, 2007). Even school-leavers have difficulty in producing, understanding and evaluating arguments (Knudson, 1991; Scherr & Hammer, 2009).

2.3.1 Addressing difficulties students experience in engaging in dialogical Argumentation

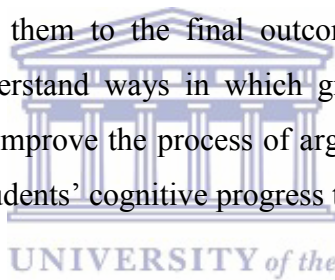
The central concern of my study has been how the participating pre-service teachers could be taught to acquire argumentation skills that enable them to use epistemic elements and strategies of argument to solve mathematical problems in physics.

What has been gained from the aforementioned studies in argumentation thus far is an understanding of the difficulties students face when they try to construct their arguments whether scientific or socio-scientific. Improving the capacity for argumentation could potentially support practice by facilitating the design of more effective learning environments (Erduran et al., 2004; Evagorou & Osborne, 2013).

While this poses particular pedagogical challenges insofar as training student teachers (pre-service teachers) in argumentation discourse is concerned, Larson and colleagues found that students' ability to evaluate arguments can be improved with a little training and by evaluating them and providing immediate feedback (Larson, Britt, & Kurby, 2009).

It is my understanding that allowing students the opportunity to participate in dialogical interaction in which claims and evidence play a dominant role, may help shift students' views of science. Viewing science as alive and changing is important for developing student epistemologies of science and encouraging student interest in becoming part of this dynamic process (Herrenkohl et. al, 1999).

By exploring the characteristics of the interactions in pairs or groups during dialogical argumentation and by comparing them to the final outcome of the groups (presentation of students' work), I can better understand ways in which groups should be scaffolded during argumentation lessons in order to improve the process of argumentation. This would then allow identification and description of students' cognitive progress through the argumentation lessons.



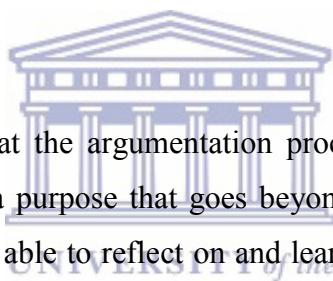
By this means the pre-service teachers could be encouraged to initiate thoughtful discussions and to develop metacognitive skills such as reflective thinking and problem solving techniques. They would thus develop skills aligned to the constructivist approach as opposed to the traditional method of teaching.

I shall also attempt to show that dialogical argumentation is a social process, which takes place in groups or pairs when students work together to construct a group argument (Kuhn, 2010).

Another approach which may help to address any difficulties with dialogical argumentation would be to explain key terms to the students, such as argumentation, claim, evidence, reasoning, counterclaim, and rebuttal. It is important to clarify terms, especially those elements with overlapping meaning, for example, claim and warrant. In practice, it is often difficult to distinguish between data and warrant when using TAP functional distinction (Van Eemeren, Grootendorst, & Kruiger, 1987).

It is thus also essential to make scientific inquiry practices explicit to the students participating in dialogical argumentation as this might help to facilitate their understanding and use of those strategies in their learning (Herrenkohl et al., 1999).

As Erduran and Jimenez-Aleixandre (2008) would argue, argumentation must be appropriated by students. It has to become part of their repertoire of skills. Towards this end explicit instruction in argumentation helps students to argue more effectively (Bell & Linn, 2000; Kuhn, 2010). In order to make instruction as explicit as possible, argumentation must be taught by teachers through suitable instruction, tasks and modelling. Studies have shown that modelling by the teacher of scientific inquiry practices helps students to use the same practice or strategy effectively (Crawford, 2000; Crawford, Kelly, & Brown, 2000). As such, the students learn by imitating their teacher, and as a consequence, develop an understanding of what counts as a good argument.



In addition, Kuhn (2010) feels that the argumentation process must be seen by the research participants to have a clear goal, a purpose that goes beyond mere simple mechanistic motion through the process. They must be able to reflect on and learn from what they are doing. In this study, the argumentation sessions emphasized this. For example, the importance of argumentation in the pre-service teachers' everyday life and in their learning of Newtonian concepts was emphasized. Newtonian concepts are not only relevant to the lives of these pre-service teachers who draw their conceptions of everyday sciences and their place in the universe from Newtonian concepts. Newtonian concepts also form part of the Grades 10-12 physical science curriculum which they will later teach when they join the teaching profession.

In the South African context, a case study conducted by Ogunniyi (2007a) investigated the effectiveness of a Practical Argumentation Course (PAC) as an instructional tool for enhancing teachers' understanding of, and ability to implement, a Science-IKS curriculum. The author explained that certain conditions are necessary if argumentation is to be done effectively. These conditions include what he described as: the ability to follow an argument (clearly a good grasp of the language used and mental alertness are critical for this to happen); a willingness to submit

to the force of a better argument; the ability to treat each other as equal and reasonable arguers; and a willingness to learn something new.

In addition to some of the necessary conditions highlighted by Ogunniyi (2007a), I think it is equally necessary for students to be given reasonable time to complete a task thoroughly. In giving their minds a chance to absorb new knowledge, true learning may be allowed to take place. Giving students time to complete a task would allow them to initiate thoughtful discussion and connections, for instance, to connect new data with an already established schema so as to invest self-gained knowledge (Piaget, 1980). This is one of the important factors in practice that this study considered carefully as will be explained in Chapter 3.

The first research question posed in Chapter 1 of the present study is about exploring pre-service teachers' ability to solve math-in-physics problems. Students' ability to solve mathematical problems in physics cannot be fully investigated outside the parameter of scientific reasoning, and proficiency in advancing, critiquing and justifying solutions to given problems, as would be the case in an argumentation setting such as DAIM. Thus, the pre-service teachers' reasoning and the type of arguments they produce while solving math-in-physics problems form vital points of investigation in the study.

2.3.2 Reasoning and Arguments

It is necessary to understand what I mean by the “reasoning and argument” students produce while solving math-in-physics problems. In other words, these processes describe essential roles and functions within science education.

To reason means to draw inferences appropriate to the situation (Britannica, 2008). Reasoning is the cognitive process of looking for reason and beliefs, conclusions, actions and feelings (Khun & Udell, 2003). In philosophy, there are two different forms of reasoning which may be used to support or justify conclusions: (1) deductive reasoning, and (2) inductive reasoning.

Regarding deductive reasoning, the condition required for it to be valid is that the argument's conclusion must be true when the premises are true. Deductive arguments thus have valid

reasoning in their content. *Inductive reasoning* contrasts strongly with deductive reasoning in that the truth of the premise does not guarantee the truth of the conclusion. Instead, there is a degree of probability in the conclusion of an inductive argument (Britannica, 2008). From this consideration it may be observed that more useful insights on reasoning discourse are best portrayed through cognitive lenses. This is something I shall return to much later in this literature review.

In the next section I discuss the theoretical framework underpinning my study. In doing so I will be guided by Silverman's (2000) view of the purpose and role of theory. Silverman argues that theory provides the principles for understanding the relationship between the factors of a complex phenomenon and how they produce their effects. Theory is helpful in identifying the object of study, revealing the nature of the object and providing the language to describe the characteristics of the various facets of the object.

2.4 Argumentation Theories and their connections to this study

The two theoretical constructs underpinning my study were chosen based on their kinship with a constructivist paradigm and their adaptability to the epistemic authorities of teaching and learning of sciences. Thus, argumentation as may be seen in the studies reviewed up to this point, has many advantages over other teaching and learning strategies. Its advantages lie in the fact that it follows the traditional deductive and inductive reasoning approach discussed earlier, which is a good instructional method for enhancing teachers' and learners' understanding of the nature of science.

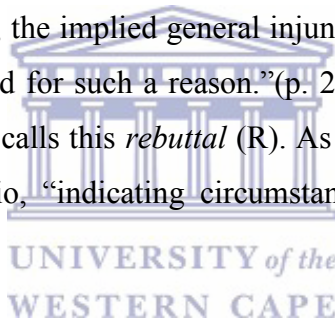
From the trends of the various studies I have reviewed, the substance of arguments such as claims, data, and warrant have been noted. Among others – yet to be mentioned – are backing, rebuttal and qualifiers. In general, to generate more insights on argumentation discourse, I turn to Toulmin's Argument Pattern (TAP) for conceptual resources.

According to Toulmin in *The Uses of Arguments*, when a *claim* (C) is being made, the claim can be challenged by a questioner who asks "what reason have you got to go on?" In such a case the person who made the claim can then appeal to relevant facts at his/her disposal, which Toulmin

calls *data* (D). Even when we have the correctness of our facts at our disposal, it may turn out to be necessary that we establish them in a preliminary argument. And whether they are accepted by the challenger or not does not necessarily end the argument.

In an alternative scenario, the challenger may ask about the bearing of our data on our claim as espoused by Toulmin “how do you get there?” In the latter case, our response will take the form: “Data such as D which entitles us to draw conclusions or to make claims such as C”. This form of proposition is what Toulmin calls a *warrant* (W) (p.98). To him, warrants (W) confer different degrees of force on the conclusions they justify, which may be signaled by qualifying our conclusions with a *qualifier* (Q) with cues like ‘necessarily’, ‘probably’ or ‘presumably’.

What Toulmin means by different degrees of force on the conclusions is that “the force of the term ‘cannot’ include, for instance, the implied general injunction that something or other has to be ruled out in this or that way and for such a reason.”(p. 28). Hence another condition during the arguments may arise; Toulmin calls this *rebuttal* (R). As such conditions of rebuttal must be mentioned, in a best case scenario, “indicating circumstances in which the authority of the warrant is set aside” (p.101).



Furthermore, the challenger may again question the general acceptability of our warrant (W), by asking: “why do you think that?” Thus, the person who made the claim will have to provide an answer that substantiates his/her thought. Such an answer is what Toulmin calls our *backing* (B). Toulmin further emphasizes various forms of backings in different fields. For example, he explains that warrants can be defended by appeal to a system of taxonomic classification, to a statue, to statistics from a census, and so on. It is this difference in backing that constitutes what he calls the field-dependence of standard arguments. To this end, all micro-arguments depend on the combination of data (D) and backing (B). If it is desirable that our backing is to be checked, then it will involve checking our claim too. Toulmin calls such arguments ‘analytic arguments’. It must be pointed out that arguments of such a kind are rare hence most arguments are not of this sort. Therefore arguments that fall within the ambit of formal criteria suffice for their assessment in what Toulmin calls ‘substantial arguments’. Any claim made must be backed up hence there is a wide variety of types of claims to be examined. Anyone’s claim has the right to

be taken seriously and examined on its own merit. Of this view, we are entitled to say that some possibility has to be ruled out only if we can produce grounds or reasons to justify this claim, and under the term 'criteria' can be subsumed the many sorts of things we have then to produce (Toulmin, 1958/2003, p. 28-29).

2.4.1 Standards for evaluating arguments

From among Toulmin's original ideas on field-dependence in his book *The Uses of Arguments*, he proposes that the standards for evaluating arguments are internal to the field to which they belong. In other words, "anything goes and nobody outside the specialists in a field can object to the standards that those specialists have developed for their intra-field arguments". The criteria then map out various fields where arguments operate. To clarify these standards, Toulmin explains that they comprise, "the grounds and reasons, by reference to which we decide in any context that the use of a particular modal term is appropriate."

For the field-dependence, one question that I considered *de rigueur* in order to keep this discussion alive is: 'Why are the evaluative criteria field-dependent?' Let us consider the following statements as ways to elicit ideas Toulmin might have offered about field-dependence: a) "You can't kill him, he is not a chicken"; b) "You can't turn him away without a cent", and c) "You can't lift that heavy load single-handedly." The form of the examples is the same but the criteria by which we evaluate them are different. For example, in the case of scenarios (a & b), criteria may encompass moral/religious points of view, as virtue is reward in itself; and c) criteria comprise of physical facts. The risk that the addressee incurs is also different: failing to live up to a moral standard, as compared to physical injury.

To buttress these ideas, we cannot reasonably just hold that any of the statements could have so many meanings: there is something common to all of them. But of course we cannot say that there is no difference in meaning, this would, in practice, just elevate one force/criteria which is the very thing Toulmin is trying to oppose. The force of the term is the same in all fields (field-independent), but the criteria for its use are different (field-dependent). To Toulmin:

"Two arguments will be said to belong to the same field when the data and the conclusions in each of the two arguments are, respectively, of the same logical type:

they will be said to come from different fields when the backing and or the conclusions in each of the two arguments are not of the same logical type” (Toulmin, 1958/2003, p. 14).

Toulmin holds that all these criteria are rational. In other words, we may have rational discussions in physics, mathematics, biochemistry and so forth. However, the standards cannot be compared against some common standard; they can only be assessed in respect to how well they achieve their own goals in relation to the subject matter treated.

Exceptions to this universalistic stance in science education research are the works of researchers who are conversant with the strengths and limitations of the model and hence have made painstaking efforts to adapt the model where feasible. In their work with teachers and students, some of these researchers referred to earlier have found that there is no common pattern in the way teachers use the model or even the same form of arguments in their classrooms. In other words, the use of argument appears to be teacher dependent (Erduran, 2006; Erduran et al., 2004; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kelly & Bazerman, 2003; Kelly & Takao, 2002; Ogunniyi, 2007a & b; Osborne et al., 2004; Simon, Erduran, & Osborne, 2005, 2006; Zohar & Nemet, 2002).

In all these studies it is concluded that the use of arguments appears to be teacher dependent.

2.5 Deficiencies of Toulmin’s Argument Pattern (TAP)

In the last five decades, authors like Habermas (1981) and Van Eemeren et al. (1987) have argued that “although Toulmin’s model is widely accepted by researchers in various fields and easy to comprehend and apply to learning activities, Toulmin does not draw the proper lines between accidental institutional differentiations of argumentation and forms of argumentation determined by internal structure” (Habermas, 1981). For example, Toulmin’s ideas of relativism would seem to depend on how strongly we interpret the field-dependency.

To judge whether Toulmin ought to be rescued from the allegedly dire consequence of his notion of relativism may be best understood in relation to Toulmin’s assertion of field-dependence.

Toulmin argues that the standards for evaluating arguments are internal to the field to which they belong. This has allegedly implied unacceptable relativism. It is understood to proclaim that anything goes and nobody outside the specialists in a field can object to the standards for evaluating arguments that those specialists have developed for their intra-arguments (Hitchcock & Verheij, 2006). To narrow the foregoing, the works from two scholars whose contentions are pivotal, may offer the best rescue for Toulmin's relativism notion. The scholars in question are Habermas (1981) and Van Eemeren et al. (1987). Within the spectre of Toulmin's ideas of relativism their contributions have been contested and their responses reformulated so as to incorporate Toulmin's initial ideas into acceptable applications in various fields.

According to Van Eemeren et al. (1987), the way Toulmin presents the "validity of an argument" is inconsistent in that in some cases he uses the formal logical meaning of "soundness" that is, based on *modus tollens* in logic, while in other cases he uses the concept for some vague general commonsensical notion of the "goodness" or "acceptability" of an argument. Despite the various objections that have been raised against the TAP, however, its great contribution lies perhaps in its rejection of a universally applicable model of argumentation (Habermas, 1981). As Van Eemeren et al. (1987) have rightly noted, the TAP has provided a useful guide for assessing argumentation in the context of a discussion between language users seeking answers to specific problems. From what we have learned so far, Toulmin claims that any examination must contain the following stages:

1. We state the problem.
2. We acknowledge that different solutions are possible.
3. We consider those that we deem possible. (This possibility is not the 'possibility' of logic; it simply means that we think they are worthy of consideration.)
4. We come to a decision.

2.6 Theoretical versus Practical Arguments

This section considers both the strengths and limitations of the type of argument expected in the present study. This section forms the essence to my study. It concerns the point I want to investigate: a realistic and feasible solution to answer the research questions. As I pointed out earlier in *The Uses of Argument* (1958), Toulmin claims that aspects of arguments [vary] from

field to field, and hence are called “field-dependent,” while other aspects of argument are the [same] throughout all fields, and hence are called “field-invariant.”

To begin with, I pose two questions to buttress this discussion: (1) What is theoretical argument? And (2) What is practical argument? Theoretical argument from an absolutist's perspective implies making inferences based on a set of principles to arrive at a claim while practical argument from Toulmin's point of view implies finding a claim of interest first, and then providing a justification for it.

In the course of many of Toulmin's works, he points out that absolutism (represented by theoretical or analytical arguments) has limited practical value. Absolutism is derived from Plato's idealized formal logic, which advocates universal truth. Viewed from Toulmin's perspective, absolutists believe that moral issues can be resolved by adhering to a standard set of moral principles, regardless of context.

By contrast, the problem with many of these so-called standard principles is that they are sometimes irrelevant to real situations confronted by human beings in everyday life, according to Toulmin. In pursuance of the former and the latter, Toulmin contends that the flaw of absolutism lies in its unawareness of field-dependent aspect of argument; hence absolutism assumes that all aspects of argument are field invariant.

In *Human Understanding* (1972), Toulmin asserts that anthropologists have been inveigled to side with relativists as they have noticed the influence of cultural variations on rational arguments. In this regard, what Toulmin is saying is that the anthropologist or relativist overemphasizes the importance of the “field-dependent” aspect of arguments, and neglects or is unaware of the “field-invariant” elements. In order to provide solutions to his contention, he then develops standards that are neither absolutist nor relativist for assessing the worth of ideas. To buttress the latter, Toulmin in *Cosmopolis* argues that the pursuit of absolutism and theoretical argument lack practicality. For example, in contrast to theoretical arguments, his practical argument is intended to focus on the justificatory function of argumentation, as opposed to the inferential function of theoretical arguments.

To this end, from the absolutists' stance, concepts are either valid or invalid regardless of context, while from the relativists' position one concept is neither better nor worse than a rival concept from a different cultural context. The tendency to treat responses from an absolutist standpoint is often imposed by the various disciplines where the argumentation process is used for evaluation. As such, concepts are either valid or invalid irrespective of the contexts in which they are being examined.

From Toulmin's stance, the evaluation depends on a process of comparison which determines whether or not one concept will improve explanatory power more than its rival concepts. Without resorting to absolutism, Toulmin believes that for a good argument to succeed, it needs to provide good justification for a claim. This, in my view, will ensure the argument stands up to criticism and earns a favorable verdict.

2.7 Modelling Conceptual Change through the Argumentation Process

As in *Human Understanding* (1972), Toulmin asserts that conceptual change is an evolutionary process. This stands in opposition to Thomas Kuhn's account of conceptual change. He believes that conceptual change is a revolutionary process during which mutually exclusive paradigms compete to replace one another. This notion held by Kuhn was criticized by Toulmin, who argued that mutually exclusive paradigms provide no grounds for comparison. Hence Kuhn made the relativists' error of overemphasizing the "field variant" while ignoring the "field invariant." Still, Kuhn believed that scientists engage in argumentation and it is through this process of argumentation within the scientific community that quality control in science is maintained (Kuhn, 1962).

Toulmin's evolutionary model of conceptual change is comparable to that of Darwin's model of biological evolution. Toulmin would argue conceptual change involves the process of "innovation and selection". To him, innovation accounts for the appearance of conceptual variations, while selection accounts for the survival and perpetuation of the soundest conceptions. Put another way, "innovation" occurs when the professionals of a particular discipline come to view things differently from their predecessors.

For example, “*gravity is a force of attraction between two objects with mass*”, is a concept that has been accepted by the scientific community from the Newtonian view of gravity for a very long time. But, another physicist by the name of Albert Einstein showed through the use of complex mathematics that gravity is not a force per se, but a consequence of the curvature of space time. Einstein discovered that massive objects bend the space time around themselves, and we perceive this bending of space time as a force.

Viewed in relation to Toulmin, “selection” would then subscribe to the “innovative” concepts in a process of debate and inquiry – what he considers as a “forum of competitions.” In this regard, the soundest concepts will survive the forum of competition as a replacement or revision of the traditional conceptions. To buttress this notion of “selection”, the example of gravity bears further comment. In the Newtonian view of gravity, light would not be affected by gravity, because it does not have mass. But for Einstein’s General Relativity, light is also affected by gravity, as has been confirmed specifically by an experiment led by Sir Arthur Eddington. They measured the real and apparent positions of stars behind the sun during a total solar eclipse. The difference between these measurements was exactly predicted by Einstein’s General Relativity. This then, in my own view accounted for the process of debate and inquiry as explained by Toulmin in his notion of innovation and selection.

Still, Newton’s idea of gravity is being taught in schools because it is a good approximation of gravity. It fails only when large forces are involved (large masses and/or small distances, for instance), as in the case of Mercury's orbit around the Sun. The limitation of space will not permit me to provide a full experimental account of Arthur Eddington's view that reveals the exact prediction of Einstein’s Theory of General Relativity. However, more details concerning this concept may be located in the research instruments with which the data has been collected. In Chapter 4 the results and discussion aim at providing further enlightenment.

In proposing provisional explanations for conceptual change, as opposed to Kuhn's revolutionary process, I locate my stance as Popper (1959) would argue: theories (or any scientific phenomena for that matter) are open to challenge and refutation. In this study, I treat each scientific concept in the research instrument that cultivates (or envisages) conceptual change as an evolutionary

process in terms of ‘innovation and selection,’ as espoused by Toulmin. This is because the interpretation of evidence and the validity of knowledge claims are at the heart of science, and are central to the everyday discourse of scientists. Beyond coherence, science often progresses through dispute, conflict, and argumentation rather than through general agreement (Kuhn, 1962; Latour & Woolgar, 1986).

2.7.1 Conception, misconception and conceptual change

Many conceptions have been found to be universal: the same conceptions occur consistently across diverse populations regardless of age, ability, or nationality of students (Hutchison & Hammer, 2010; Osborne & Freyberg, 1985; Pfundt & Duit, 2006). These conceptions are sometimes held by learners and their teachers who construct scientific concepts which differ from accepted scientific ideas (Scott, Asoko, & Driver, 1992). These conceptions are remarkably resistant to change using conventional teaching methods (Wandersee, Mintzes, & Novak, 1994).

Wandersee et al. (1994) have identified a variety of sources of such conceptions held by learners and teachers. These include parallels from history, use of intuitive rules, prior experience, use of language, and even instruction. According to Kang, Scharmann, Noh, and Koh (2005), conceptual change is the most significant learning model that evolved from the “conceptions movement” and posits that “learning consists of iterative interactions that take place between students’ existing conceptions and their new experiences.”

In response to these studies, Posner, Strike, Hewson and Gertzog (1982) suggest that four conditions – dissatisfaction, intelligibility, plausibility and fruitfulness – should be met in order to replace non-scientific conceptions held by students. This inspired a number of teaching strategies to promote conceptual change. Among them, a cognitive conflict strategy has been commonly incorporated in most conceptual change models (Chan, Burtis, & Bereiter, 1997; Pintrich, 1999).

A cognitive conflict can be produced by various situations, such as the experience of a cognitive gap. This occurs when the person involved is vaguely aware that something within his/her knowledge structure is missing (Hewson & Hewson, 1984; Strike & Posner, 1992).

Cognitive conflict has often been induced by discrepant events – presenting information and/or experiences that clearly contradict students’ existing conceptions. When two conceptions are in direct conflict with each other, it becomes problematic.

The usual cognitive conflict paradigm involves: (a) identifying students' current state of knowledge; (b) confronting students with discrepant events and (c) evaluating the degree of change between students' prior conceptions and a post-test measure after the instructional intervention (Limón, 2001). However, when a conflict arises in the mind of the student as a result of being exposed to school science, the contiguity argumentation theory (CAT) suggests that a sort of “internal argument” or “conversation” ensues within him/her (at the microneuro-psychical level) between competing schemata in the working memory where consciousness in an individual is assumed to be most active (Le Doux, 1999; Ogunniyi, 1997). This provides more grounds why the inclusion of CAT is deemed necessary for the present study.

Furthermore, CAT suggests that argumentation processes also occur at the macro-social level, that is, between people involved in a conversation or an argument (Ogunniyi, 2007a). In the same vein, a considerable number of researchers have argued that cognitive conflict strategies tend to promote conceptual change. They include: (Amin, 2009; Chan, Burtis & Bereiter, 1997; Druyan, 1997; Hewson & Hewson, 1984; Kuo et al., 2013; Posner, Strike, Hewson, & Gertzog, 1982). However, some researchers claim that cognitive conflict strategy does not necessarily lead to conceptual change. These include: (Chiu, Chou, & Liu, 2002; Dekkers & Thijs, 1998; Dreyfus, Jungwirth & Elovitch, 1990).

A certain number of studies have suggested that students in many cases do not necessarily experience cognitive conflict merely by encountering discrepant events. These studies include those of (Chi, 2008; Chinn & Brewer, 1998; Mason, 2001; Ozdemir, 2013). That said, it seems there is a need for further studies to clarify several unresolved issues. As a way of finding common ground, the researcher explored additional studies based on argumentation.

2.8 Difficulties various studies have encountered using TAP and some useful suggestions

As a way to ameliorate the problem at hand, and in response to the demands of the emerging multicultural society in South Africa, I explored studies that have used TAP in science classrooms. As pointed out earlier, TAP has been used increasingly by science educators in recent years. For example, educational researchers have used Toulmin's model to investigate arguments in a number of subject areas. Kelly, Druker, and Chen (1998) applied TAP to the analysis of student language (dyadic spoken) discourse and found methodological problems. Consequently they found that organizing student discourse into Toulmin's argument components served to focus attention carefully on the contextualized use of language.

Kelly et al. (1998) have explained that while the TAP makes distinctions between statements of data, claim, warrant, and backing, it is restricted to relatively short argument structures and the argument components pose ambiguities. They proposed statements of claims can serve as a new assertion to be proven or can be in service to another claim, as such acting as a warrant.

Also, there have been questions around the issues of what the quality of argument is and ways by which to determine its strength. As noted earlier, Toulmin articulated a view of an argument as having both a macro- and micro- structure comprising a series of claims supported by evidence and warrants or refuted with rebuttals and counter claims (Jimenez-Alexandre, 2002). According to Toulmin, the quality of arguments should not be judged on the basis of individual components, but rather on their overall structure (Berland & Reiser, 2009; Chinn, O'Donnell, & Jinks, 2000; Clark, Sampson, Weinberger, & Erkens, 2007).

Despite the frequent use of TAP by science educators, criticisms directed at it have not stopped. Of course, Toulmin, in the array of his ideas, does not embrace perfection; he seems to welcome refutations around his works especially in *The Uses of Argument*. I believe that what lies behind this relates largely to the fact that the application of TAP to the analysis of classroom-based discourses has yielded difficulties (if not questions, then answers). For example, the main difficulty has been in the clarification of what counts as a claim (C), data (D), warrant (W), and backing (B). For this reason I now turn to the works of other scholars who have painstakingly found ways through which the shortcomings may be handled.

In addition to the foregoing ideas, other exemplary scholars who have also encountered various problems using TAP include (Duschl, Ellenbogen, & Erduran, 1999). In their study they prefer other analytical tools such as Walton's work (1996) scheme on presumptive reasoning, justifying their choice on the ambiguity surrounding the key features of TAP in the application to real discourse. In this regard, Erduran et al. (2004) alluded to the difficulty of distinguishing various components of Toulmin's argument, particularly data, warrants and backings which were already exposed by other scholars (Kelly et al., 1998).

Furthermore, Erduran et al. (2004) have suggested that one way of distinguishing them could be to use words such as "because", "so" or "since" as cues to indicate data/evidence, claim and warrant, respectively. This indicates one way in which they resolved the ambiguities, hence the use of the operative word "so" which itself is implied in Toulmin's definition for reaching conclusions. In addition they have simplified the elements of TAP by designating data, warrants, backings and qualifiers as grounds. This arrangement immediately removes the contentions that have been raging around the elements of TAP (Ogunniyi, 2007a).

In line with the suggestion made by Erduran et al. (2004) it is hoped that by going beyond the TAP scheme as espoused by Toulmin (1958/2003) inclusion of these cues "because", "so" or "since" would prove handy in the training of pre-service teachers on dialogical argumentation in classroom discourse. Toulmin recognizes an argument as comprising a claim (C), data (D), warrants (W), backings (B), qualifier (Q) and rebuttals (R) as depicted in Figure 2.1.

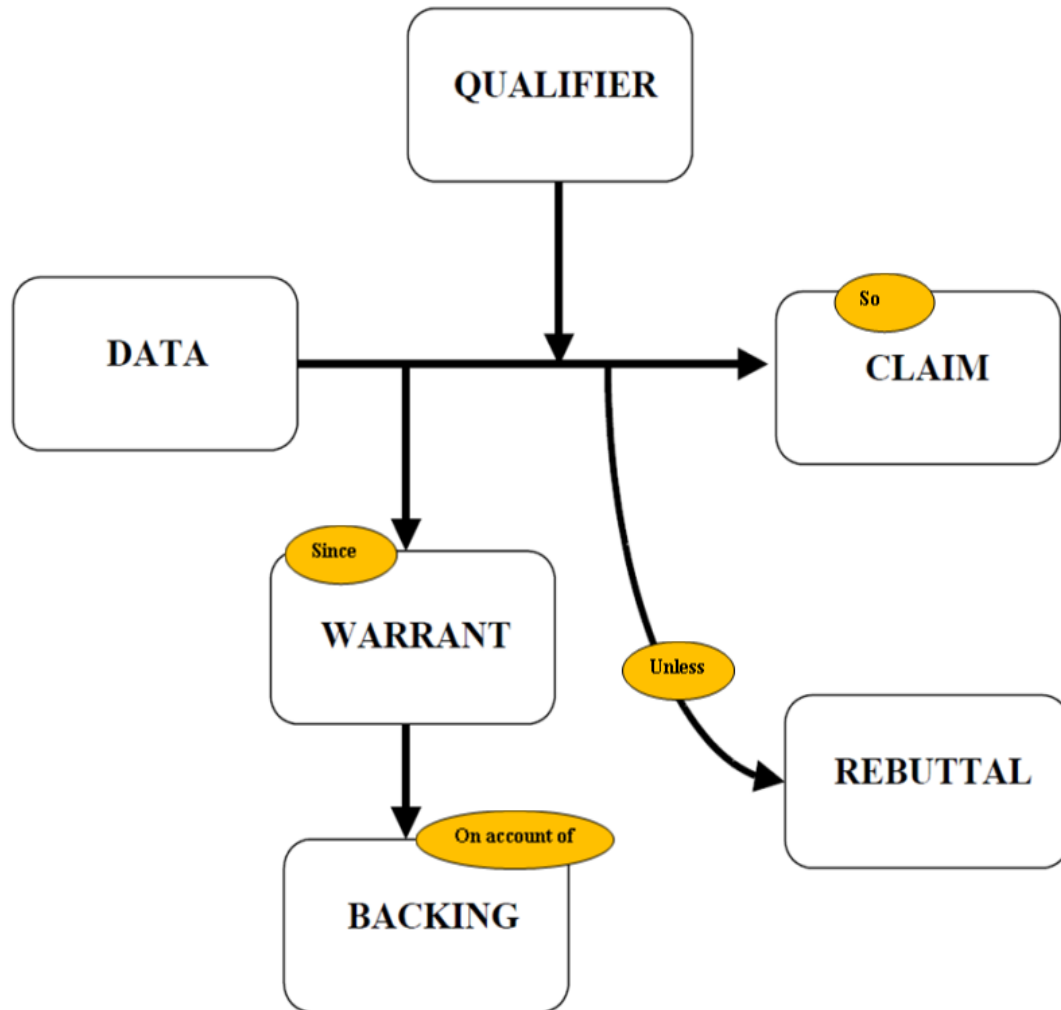


Figure 2.1 Toulmin's Pattern of Argumentation, (After Erduran et al., 2004; Toulmin, 1958/2003)

As already indicated, Erduran and her colleagues have used the TAP model first as a teaching strategy for teachers to instill scientific reasoning skills in their learners, and then as a research tool for analyzing classroom discourse. These main elements of TAP – claims; warrants; backings; qualifiers; and rebuttals – are therefore deemed necessary to address how the pre-service teachers construct an argument to justify their solutions to given mathematical problems in physics. The six features of argument espoused by Toulmin are summarized in Table 2.1.

Table 2.1 The main features of TAP as espoused by Toulmin

| Features | Content of Argument (<i>logically oriented</i>) |
|------------------|---|
| Claim | Assertion about what exists or values that people hold: It is a conclusion whose merits are to be established through argumentation or through the statement being argued. |
| Data | Statement that is used as evidence to support the claim: the facts or evidence used to prove the argument. This means the facts that those involved in the argument appeal to in support of their claim or refute in another's knowledge claim. |
| Warrant | Statement that explains the relationship of the data to the claim: logical statements that serve as bridges between the claim and the data. These are the justifications for moving from specific grounds or evidence to specific claims (Bricker & Bell, 2008). |
| Qualifier | Special condition under which the claim holds true: statements that limit the strength of the argument or statements that propose the conditions under which the argument is true. Put another way, contingent conditions on which the claim is based. |
| Backing | Underlying assumption that is often not made explicit: statements that serve to support the warrants – arguments that don't necessarily prove the main point being argued, but which do prove the warrants are true. |
| Rebuttal | Statement that contradicts the data, warrant, backing or qualifier of an argument: counter-arguments or statements indicating circumstances when the general argument does not hold true. |

(Source: Toulmin Argument Pattern (TAP) modified after Simon, Erduran and Osborne, 2006)

Toulmin's argumentation pattern (TAP) offers a useful tool for arguing in informal settings such as in socio-scientific and scientific contexts where informal logic is applicable. However, the way TAP has been applied in many studies has been criticized in terms of the inconsistent means by which the validity of an argument is established (Van Eemeren et al., 1987).

For example, in their study Means and Voss (1996) proposed three levels of argument structure: skeletal, enhanced, and elaborated. A skeletal argument has one claim supported by one reason. An enhanced argument has one claim supported by one reason plus two or more qualifiers and an

elaborated argument has two or more claims supported by two or more reasons plus two or more qualifiers.

Chinn, O'Donnell and Jinks, (1998, 2000) graded argument structures from low to high. Low level arguments have simple reasons supporting claims while high level arguments are composed of complex networks of multiple sub-arguments and rebuttals.

In juxtaposition to these studies, Downing's model cited in Naylor, Keogh and Downing (2007) focuses on the nature of the interaction between individuals rather than on the content of the argument itself (as in Toulmin, 1958/2003). Downing's model has seven levels which attempt to identify and differentiate the nature of the interaction (see Table 2.2). Thus, a focus on the individual takes no account of the quality of the interaction.

Table 2.2 Downing (2007) Analytical model of argumentation

| Level | Description of Arguments |
|-------|---|
| 1 | Students are unable or unwilling to enter into discussion |
| 2 | Students make a claim to knowledge but offer no evidence to support the claim |
| 3 | Students begin to offer evidence to support their claims |
| 4 | Students offer further evidence to support their claims |
| 5 | Students respond to ideas from others in the group |
| 6 | Students are able to sustain an argument in a variety of ways |
| 7 | Students evaluate the evidence and make judgments |

Also, Schwarz, Neuman, Gil and Ilya (2003) arranged argument structures into a hierarchy ranging from simple claims to compound arguments. Thus, high level argument structures involve multiple perspectives that are supported by rich evidence. This notwithstanding, TAP has at times been seen by many authors as vague due to the way in which the theoretical, methodological and analytical frameworks have been used. One consequence is the overlaps between its elements (Van Eemeren et al., 1996) and the inherent assumption about the passivity of the opponent in influencing the proponent's argument (Leitaño, 2000).

To address some of these issues Erduran et al. (2004) used the frequency of rebuttals to judge the quality of an argument – the greater the number of rebuttals, the higher the quality of that argument. This is very important for the present study as it is likely to enhance components of teaching processes of the physics content and can help the pre-service teachers to better understand the knowledge to be taught. Also, as indicated earlier, they used claims, grounds (evidence, warrants, backings and qualifiers) and rebuttals to reduce the overlaps among the elements of TAP.

Additionally, research indicates that as rebuttals become more clearly identifiable the quality of arguments improves (Clark, Sampson, Weinberger, & Erkens, 2007). In other words, rebuttals indicate the quality of arguments in that they challenge participants to evaluate the validity and strength of arguments (Erduran, 2007). Put another way, rebuttals are evidence of the development of cognitive argumentation skills (Kuhn, 1991). For example, Erduran et al. (2004, p.928) devised an analytical framework that has five levels to show quality of an argumentation (see Table 2.3).

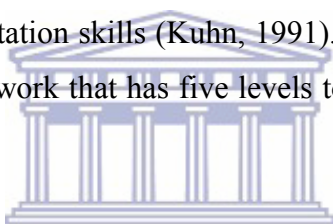


Table 2.3 Analytical Framework Used for Assessing Quality of Argumentation

| Level | Description of Arguments |
|--------------|--|
| 1 | Arguments that have a simple claim versus a counter-claim, or a claim versus a claim |
| 2 | Arguments that consist of a claim versus a claim with either data, or warrants, or backings [but that] do not contain any rebuttals |
| 3 | Arguments with a series of claims or counter-claims with either data, warrants, or backings and with the occasional weak rebuttal |
| 4 | Arguments with a claim with a clearly identifiable rebuttal, for example <i>an argument that has several claims and counterclaims</i> |
| 5 | An extended argument with more than one rebuttal |

Adapted from Erduran, Simon and Osborne (2004)

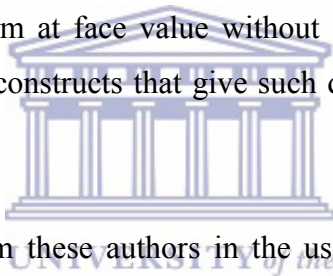
Even though argumentation structure and rebuttals are good indicators of argumentation skills, as seen from the quantum of research studies carried out on argumentation, it is nonetheless difficult to directly connect them to the development of classroom argumentation activities.

Thus, it is important to understand the processes and activities through which students develop argumentation skills in the classroom.

Hence the present study is concerned with understanding the dynamics of argumentation in a physics class discussion. Here it was used to develop pre-service science teachers' abilities to solve mathematical problems in physics for the purpose of improving their didactic methodological repertoire (teacher self-efficacy).

In the South African context, a case study done by Ogunniyi (2007a) has identified further TAP shortcomings. The author states:

... another problem with the TAP is whether or not we can accept a set of data forming the basis of a claim at face value without considering the underlying assumptions or theoretical constructs that give such data specified meanings (p. 966).



I think what has been gained from these authors in the use of TAP is that several questions remain concerning its methodological constructs, hence the overlapping elements such as data and warrant as pointed out by (Van Eemeren et al., 1987). But despite the TAP's shortcomings, it is still seen as the most influential model of argument structure. From the late 90's to date, educational researchers have used Toulmin's model (TAP) to investigate arguments in a number of subject areas (Driver et al., 2000; Erduran et al., 2004; Jimenez-Aleixandre & Erduran, 2008; Kelly et al., 2007; Kuhn, 2010; Lubben et al., 2010; Muller-Mirza, Perret-Clermont, Tartas, & Iannaccone, 2009; Ogunniyi & Hewson, 2008; Osborne & Patterson, 2011). In addition to these studies it is important to take into account the context in which argumentation occurs (Billig, 1987).

Supplementing the foregoing studies, Ogunniyi (2007a) in his study outlines different types and levels of arguments, serving a variety of functions, concluding that it is not feasible to use a single model to represent all forms of arguments. To take this further I now present the Contiguity Argumentation Theory by Ogunniyi (2004, 2007a & b).

2.9 The Contiguity Argumentation Theory CAT

CAT, rooted in the Contiguity Theory, is a learning theory traceable to the Platonic and Aristotelian era (Ogunniyi, 2007a & b). According to Ogunniyi (2007a), the Contiguity Argumentation Theory (CAT) deals with both logical, or scientifically valid arguments, and non-logical metaphysical discourses embraced by IKS. The Aristotelian contiguity concept states that one or two states of mind (or, as applied in CAT, two distinct co-existing thought systems such as science and IKS), tend to readily couple with, or recall each other to create an optimum cognitive state.

Although CAT to some extent draws on the Aristotelian contiguity notion, it regards such elemental ideas not as “concrete referents” but as dynamic organizing conditionals or “frames of reference” that galvanize the process of association or learning in general depending on the context in question (p.162). Likewise, CAT draws on the African worldview theory of Ubuntu which stresses the interdependence or interrelatedness of ideas. In other words, ideas find full expression and authentication in the collective ideas of others or the society at large. More of the implications of this view will be addressed in the discussion concerning the dialogical argumentation instructional model (DAIM) adopted in this study.

Ogunniyi explains what is proposed by the CAT theory is that claims and counter-claims on any subject matter within (or across) fields can be justified only if neither thought system is dominant. Hence there must be valid grounds for juxtaposing the two distinctive worldviews within a given dialogical space.

Thus the role of such a dialogical space is to facilitate the process of re-articulation, appropriation, or what he calls negotiation of meanings of the different worldviews, for example, in science and IKS. Students must therefore be able to negotiate the meanings across the two distinct thought systems in order to integrate them. This is because CAT assumes that ideas that come together will interact, overlap, or conflict with each other. In other words, when ideas clash, an internal dialogue occurs to find some meaningful form of coexistence.

One way of integrating such systems of thought is by finding or adapting them to a larger synergistic milieu of conceptualization (Ogunniyi, 1997). Ogunniyi explains this may lead to a higher form of awareness and consequently to a deeper level of understanding than was previously possible. Essentially, CAT recognizes five categories into which ideas may move within a person's mind when discussing issues of different thought systems. In the section that follows, I shall expand upon this point.

2.9.1 Five Adaptive Cognitive States of CAT

Essentially CAT consists of five dynamic cognitive states that the pre-service teachers might use to appraise, and to adapt to different contexts of mathematical problems in physics. The five categories are: dominant, suppressed, assimilated, emergent, and equipollent, depending on the nature of the arousal context or the claims to be defended or refuted in the strife to attain a sort of cognitive allostasis. What Ogunniyi means by "allostasis" or "homeostasis" in neuro-scientific terms is the process of achieving stability, through physiological or behavioral change (Ogunniyi, 2007a, p. 970). Since "different circumstances demand different homeostatic set points" (Sapolsky, 1994, p.7), five adaptive cognitive states could occur within a learner confronted with counter-intuitive school science. The five adaptive cognitive states are summarized in Table 2.4 below.

Table 2.4 The five Stages of CAT as proposed by Ogunniyi

| CAT Stages | Adaptive co-existence that occurs within a learner confronted with two distinct forms of thought/constructs (<i>Logical and Non-logical features</i>) |
|------------------------------|---|
| Dominant (1) | One thought system or explanation is seen to be more convincing or more appropriate than the other thought system or explanation at that moment and for that context; or a powerful idea explains facts and events more effectively and convincingly than another idea or resonates with the acceptable social norm that affords an individual a sense of identity. |
| Suppressed (2) | One thought system is seen to be less convincing than another. The less convincing, subordinate or culturally less acceptable thought system becomes suppressed. An idea becomes suppressed in the face of more valid, appropriate, adequate and convincing evidence. |

- Assimilated** (3) The dominant thought system is taken by people who initially held the suppressed thought system as the standard. The initially held thought system is supplanted or subsumed by the dominant worldview. This means that a less powerful, less convincing idea is assimilated (taken in, swallowed by) a more powerful or more persuasive idea.
- Emergent** (4) No previous idea, opinion or position on an issue really exists in the learner. For instance, an idea may emerge as the individual is exposed to new teaching-learning experience as is normally the case with science concepts learnt at school. Alternatively, an indigenous knowledge may be learned by listening to others in class. The learner then adds the new concepts to his repertoire of knowledge (Ogunniyi, 2011).
- Equipollent** (5) Two competing thought systems are seen as equally powerful, adaptable, active, effective or significant for making sense of the observed phenomena. The two rival thought systems coexist and exert equal cognitive force on a person's beliefs. For example, a person could find both theories of creation and evolution as attractive explanations for the origin of the universe and humankind (Ogunniyi, 2011).

(Source: Contiguity Argumentation Theory (CAT) adapted from Ogunniyi, 2007a & b)

Each of these cognitive dimensions is in a dynamic state of flux and can change from one form to another depending on the context in question (Ogunniyi, 2007a). Viewed thus, I seek to establish: (1) what causes the dynamic state of flux in each of these cognitive dimensions; and (2) if the change that occurs in each of the cognitive dimensions is context-dependent, which context is likely to forestall change.

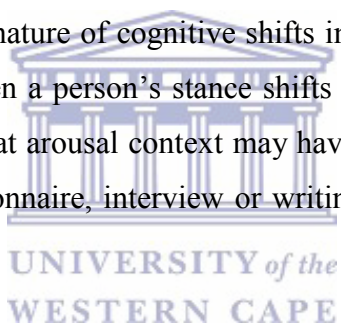
According to this theory then, when both the mathematics and the physics concepts are cognitively assimilated, when these ideas are rooted in the structure of math-in-physics content itself, none need dismiss one in preference to the other in their history and the development of their fields of application. Thus, the pre-service science teachers should be presented with the two notions and allowed to choose on the basis of the context and arguments.

The limitation of space will not permit repeating several excellent reviews of studies that have employed CAT in argumentation-based approaches in the study of teachers' and pre-service teachers' conceptual understanding of science phenomena, hence it is virtually impossible to

ignore those that merit close attention (Govender, 2014; Hewson & Ogunniyi, 2011; Ogunniyi, 2006, 2007a, 2007b).

Findings emanating from a plethora of studies have not only highlighted the importance of arguments and dialogues in enhancing teachers', pre-service teachers' and learners' conceptual understanding of scientific phenomena, but have also increased their awareness on how to sharpen their ability to think critically in a scientific context. In this study, pre-service teachers were exposed to an argumentation framework based on Toulmin Argument Pattern (TAP) and Contiguity Argumentation Theory (CAT) by Ogunniyi (2007a & b).

Apart from the dialectic effects of the CAT in scaffolding argumentation for the pre-service teachers involved in the study, CAT also fitted nicely as a unit of analysis. It functioned as a means by which to determine the nature of cognitive shifts in an argumentation milieu. In other words, it is easy to determine when a person's stance shifts from a logical to a non-logical yet socially acceptable stance, and what arousal context may have been responsible for such a shift. Their responses to the test, questionnaire, interview or writing could easily reveal this by mere inspection.



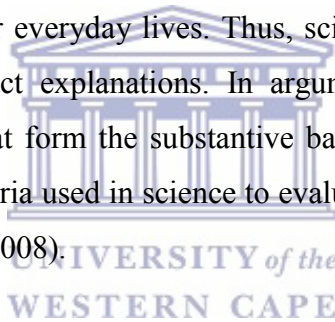
2.10 Argumentation in classroom: writing, constructing and evaluating arguments

From an educational perspective, it is understood that teaching students to recall scientific facts, laws, and theories is not enough. It is important for them also to know why scientific knowledge and ideas have merit and why these may be trusted (Bell & Lederman, 2003). One unobtrusive way of achieving this is by integrating argumentation skills into instructional activities that involve writing, constructing and evaluating arguments (Lu & Zhang, 2013). However, teaching students to write, construct and evaluate arguments poses pedagogical challenges for teachers (Kelly, Regev, & Prothero, 2007). Acquiring such skills involves more than simply learning to engage in oral debates (Lu & Deng, 2013).

The problem facing students regarding the acquisition of argumentation skills requires not only the development of basic literacy skills, but also the ability to examine, compare and select diverse facts. These may be logical and non-logical facts, ideas, arguments and opinions from a

variety of written sources. Students would have to anticipate and rebut objections or disagreements (Muller Mirza et al., 2009). In the same vein, Lu and Zhang (2013) argue that students must be able to analyze and evaluate the arguments they read in order to write effective arguments. One way in which this might be incorporated into the present study practically would be if the pre-service teachers were to be taught how to interpret the problem statement of an argument, extract and examine ideas, and organize and compare perspectives and opinions from other viewpoints. This could be done, for example, with viewpoints from other groups/individuals in the DAIM setting, from which information to be used in writing arguments may then be selected and analyzed.

According to Means and Voss (1996) knowing the characteristics of scientific knowledge and the way it is constructed will make it easier for citizens to distinguish good science from bad and apply scientific knowledge to their everyday lives. Thus, science education requires a focus on how evidence is used to construct explanations. In argumentation discourse this means to examine the data and warrants that form the substantive basis of belief in scientific ideas and theories and to understand the criteria used in science to evaluate evidence (Osborne, Erduran, & Simon, 2004a; Simon & Newton, 2008).



In view of its effectiveness, argumentation instruction could be used to revive students' declining interest in physical science especially those whom the pre-service teachers involved in the study will later on teach in high school (Grades 10–12) in South Africa. One reason for this enthusiasm is that many studies have found that argumentation instruction allows many more students to participate freely in classroom discourse, to clear their doubts and even to change their views than would otherwise have been the case within a traditional teacher-dominated instruction model (Erduran et al., 2004; Ogunniyi, 2007a & b; Osborne, Erduran, & Simon, 2004a).

2.11 Studies from certain Universities in South Africa relevant to the present study

In the Western Cape Province, Cape Town, South Africa, there are four universities and six technical colleges, which fall within the ambit of the Further Education and Training (FET) band. The four universities are the Cape Peninsula University of Technology (CPUT), the University of Cape Town (UCT), the University of the Western Cape (UWC), and the University

of Stellenbosch (US). In South Africa Further Education and Training (FET) refers to education and training provided from Grades 10-12, including career-oriented education and training offered in technical colleges, community colleges and private colleges.

At the time of the present study there are six Further Education and Training (FET) colleges in the Western Cape: College of Cape Town, False Bay College, Northlink College, West Coast College, Boland College and South Cape College. These FET colleges with campuses in more than thirty-six suburbs and towns are playing a growing role in the provision of the intermediate to higher level skills required to support economic growth and development in South Africa.

In keeping with the universities, the present study was conducted in one of the four abovementioned universities. Interestingly, all four universities provide teacher training programs aimed at preparing professional teachers for the Foundation Phase, General Education and Training, Intermediate Senior Phase, Further Education and Training and so forth. Various studies have been done in these programmes and the findings, recommendations and implications have initiated amendments, revision of programmes, staff development and major shifts in the way teaching and learning takes place in lecture theatres. Some studies have focused on curriculum development and managerial protocol. Other studies have focused on pre-service teachers, teachers and the students they teach. It is the latter that this research shall focus on.

In the last decade science education has turned to argumentation as a possible strategy to help teachers and learners transition to the learner-centred methods expected in the new South African curriculum (Ogunniyi, 2007a). Based on the various argumentation models outlined in this chapter, it is evident that an analysis of classroom argumentation data is not always straightforward and that no one model can be applied satisfactorily in all contexts. Thus, argumentation research is still relatively new in South Africa. In two out of the four universities in the Western Cape, studies similar to the present study have been conducted. These I believe merit attention here because not only were they conducted using pre-service teachers in the same location, but other significant factors account for this as outlined in the section that follows.

- The two studies share the same theoretical framework with the present study.
- They drew their samples from the same background pool with the present study.

- Like the present study the two studies focus on FET programs.
- They share similar concerns (or objectives) in terms of adapting a methodological approach that suits non-Western science students (African science students).
- They pursue the same subject matter as the present study (that is, the sciences).

One of the two studies was conducted in the same faculty as was the present study.

Findings from the two studies and the present study may constitute a set of guidelines for teacher training programs aimed at equipping Grades 10 – 12 science teachers. Drawing on the rationale for the inclusion of the two studies conducted in two of the four universities in the Western Cape, the researcher now discusses them in depth. The two studies of interest are the works of Ogunniyi (University of the Western Cape), Scholtz et al. (2008) (Cape Peninsula University of Technology). In South Africa, studies on Argumentation have focused on both science concepts and Socio-scientific issues (Ogunniyi, 2007a & b).

What poses a challenge for many South African learners (and teachers) is the requirement for argumentation strategies in the implementation of the new curriculum. It stipulates that teachers are to include Indigenous Knowledge (IK) in science lessons (Ogunniyi, 2007a & b, 2008). These challenges relate to Ogunniyi's assertion that South African learners and teachers uphold a diversity of thought systems including various religious and cultural beliefs, indigenous knowledge systems, and what he terms commonsensical and intuitive notions (Ogunniyi, 2007b). Because of such challenges, Ogunniyi explains, the learners often find themselves confronted with different thought systems during the course of science teaching and learning under the new curriculum (p.1190).

Given the South African history of Apartheid, one cannot negate the fact that much valuable wisdom has been lost in South Africa, also over the past 300 years, and effort is now needed to rediscover it and examine its value for the present day. The prevailing world-view of science is based on empiricism. However, it is important that the Natural Sciences curriculum take into account the existence of different world-views. Ogunniyi (2007b) cites the Revised Science curriculum Statement as asserting that: "One can assume that learners in the Natural Sciences

Learning Area think in terms of more than one world-view. Several times a week they cross from the culture of home over the border into the culture of science and back again” (p. 1190).

These South African issues create interesting challenges for curriculum policy, design; materials and assessment. These challenges Ogunniyi believes can be tackled using a dialogical argumentation instructional approach. In order to explore the nature of argumentation in this context, he formulated the Contiguity Argumentation Theory (CAT) and concomitantly, the dialogical argumentation instructional model (DAIM) (Ogunniyi, 1997, 2004, 2007a). Findings based on applications of Ogunniyi’s CAT and DAIM suggest that a variety of possible interactions is to be expected if argumentation activities are to be used in South African classrooms with such a wide diversity of learner backgrounds.

Ogunniyi’s work has shown the positive effects of in-service professional development programmes using argumentation as a strategy in shifting teachers' conceptions of the nature of science (NOS) and the nature of indigenous knowledge systems (NOIKS) (Ogunniyi, 2007b, 2007c; Ogunniyi & Hewson, 2008).



In the next section, I discuss the work of Scholtz and colleagues based on a study they conducted at the Cape Peninsula University of Technology.

Scholtz and her colleagues’ study focused on the development of argumentation skills among pre-service science teachers enrolled in a teacher training program. Using the Toulmin Argument Pattern (TAP-model), Scholtz and her colleagues observed a unique form of engagement among teachers, which they termed inclusive argumentation (Scholtz et al., 2008). Scholtz and her team found that their research participants engaged in a unique style of argumentation which precluded rebuttals; they used argumentation as one of the teaching strategies. Research participants’ disagreements were either in the form of an affirmative statement followed by a counter claim/alternative warrant or they were phrased as a question (Scholtz et al., 2008).

The findings of the foregoing study have also provided important information about the nature of interaction in small group discussions (Scholtz et al., 2008). Although the complementary

findings from the works of Ogunniyi, Scholtz and colleagues have given hope for a didactical approach to teaching African pre-service science teachers in these two universities in the Western Cape, more still needs to be done with respect to the training of physics teachers. The task of making the curriculum work (Bak, 1999) has by no means diminished. It is against this background that the present study drew its inspiration for selecting a theoretical framework for this study.

This study has drawn points for further inquiry from the foregoing studies reviewed. As noted, these derive from certain variables which differ from one another in certain ways. Even though many of the studies reviewed so far have focused on teachers', pre-service teachers', and other students' exposure to dialectic or collaborative argumentation, these studies were not specifically concerned with solving mathematical problems in physics. This prompted a study whose aim it was to investigate pre-service teachers' *ability* to use the dialogical argumentation instructional model (DAIM) to solve mathematical problems in physics. It is therefore apposite to determine what that ability entails – ability being a complex variable. Based on research gaps identified in the other studies referred to here, a focus on the processes associated with cognitive ability in relation to dialogical argumentation was deemed essential.

From a didactic viewpoint, learning has often been seen as a complex issue. This is because learning activities are not rigid. No study can say it has documented a single instructional approach that addresses all the concerns associated with teaching and learning. Nor can any claim to have answer(s) to all the questions challenging teachers and students of all ages in the world. In this regard, Vygotsky's (1978) point that human development and learning originate and develop from social and cultural interaction is crucial. At issue here are social characteristics, communication styles, personality, cognitive ability, linguistic styles, and academic background. In this review, it is therefore essential to examine socio-cultural issues as these play a critical role in the thinking process.

2.12 Cognitive ability processes and problem recognition

Cognitive ability involves knowledge and the development of intellectual skills. This includes the recall or recognition of specific facts, procedural patterns, and concepts that serve in the development of intellectual abilities and skills (Krathwohl, 2002).

On the basis of this assertion, investigating whether a student knows “Z” will inevitably include watching him/her do something that closely resembles “Z”. If knowing and doing are so closely intertwined (Brown, Collins, & Duguid, 1989), one should not ignore the real-world setting in which the student does “Z”. For example, a physics student may show evidence that s/he knows

the fourth equation of the Lorentz transformation $t' = \frac{t - \frac{v}{c^2}x}{\sqrt{1 - \frac{v^2}{c^2}}}$ by stating the equation without

prompting. But, stating the equation may not satisfy other indicators of understanding such as recognizing the interplay between each symbol and any other with which it may appear. Thus, a physics student who has a sound knowledge of the equation would know that time difference $\Delta t'$ of the two events with respect to K' in general does not vanish, even when the time difference Δt of the same events with reference to K vanishes. In essence, pure “space-distance” of the two events with respect to K results in “time-distance” of the same events with respect to K' . A student who is able to illustrate all these ideas has shown that s/he comprehends the equation and its meaning.

Moreover, a student’s recognition that the most essential property of this equation shows a pronounced relation to the three-dimensional continuum of Euclidean geometrical space might indicate that the student has demonstrated concept recognition. Studies have shown that one major factor hindering students’ cognitive ability in problem-solving is the lack of problem recognition (e.g., Finkelstein, 2005; Larkin & Reif, 1979; Russ, Scherr, Hammer, & Mikeska, 2008).

Without clearly recognizable basic problems, a composite problem becomes just one big problem and tends to be treated by less skilled problem solvers attempting to derive solutions in

the same way as basic problems. Difficulty in recognition affects other cognitive factors such as the strategy employed in creating a solution procedure and how the procedure is represented (Laughlin, Harold, & Norbert, 2008).

A fairly recent study done by Kuo et al. (2013) have supported the assertions of Russ et al., (2008) and Heller, Keith and Anderson (1992) that one way to facilitate problem recognition is let the skilled and less skilled problem solvers alike concentrate on key words in the problem statement. Having recognized a problem or its components, it is then necessary to use some strategy to obtain a solution path leading from the information given in the problem statement to the goal (the required answer).

It is thus clear that research in cognitive science on math-in-physics problem solving can inform physics educators of the current state of affairs and can even suggest constructs that promise powerful ways of thinking about teaching problem solving. For example, general cognitive ability (as mediated by knowledge structures), improved retention of a complex skill in a video analysis for insight, and coding of introductory physics problem-solving (Scherr, 2009).

2.12.1 Cognitive Processes for Retention and Transfer of learning

In general, retention focuses on the past and is closely related to “Remember”, whereas transfer emphasizes the future and is increasingly related to the other five cognitive process categories: Understand, Apply, Analyze, Evaluate, and Create.

According to Mayer and Wittrock (1996) retention is the ability to remember material at some later time in much the same way as it was presented during instruction, while transfer is the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter.

Mayer (2002) explains that when retention and transfer occur, they indicate meaningful learning. What Mayer (2002) does not elucidate is how teachers may facilitate retention and transfer among students. It is Wagner's view that retention requires that students remember what they have learned (Wagner, 2010), whereas it is Mayer who claims that transfer requires students not only to remember but also to make sense of and be able to use what they have learned (Mayer, 2002).

But if retention (of prior knowledge), and transfer (recall, sense-making, and ability to apply what has been learned) are to be inculcated in students, then establishing a link between cognitive ability and concept recognition should lead to the acquisition of conceptual resources for problem-solving.

2.13 Socio-cultural Constructivism

In this section, I will address socio-cultural issues only “from the inside” – that is, from the point of view of the pre-service teachers involved in my study and their cognitive responses to both the socio-cultural and physical environments. It is generally accepted that the education of a student is an immensely complex issue. This is because each individual lives in many cultures and is educated in many social environments that play a major role in what the student learns and does not learn. There is great emphasis on the behavior of an individual in response to conceptual learning– particularly in the context of the learning of science and physics. However, most of my examples are taken from the field of physics.

According to Redish (2004) every individual’s thinking processes has been shaped by being raised within a culture and these processes both respond to and shape the cultural environments in which individuals find themselves. It is noteworthy that emphasis is placed on how the individual’s cognition responds to both the socio-cultural and physical environments. Even if we are primarily interested in socio-cultural phenomena, what is learned from the individual cognitive perspective is useful. This is because a cognitive view assumes the existence of perturbing environmental influences while it takes into account the individual's active thought processes.

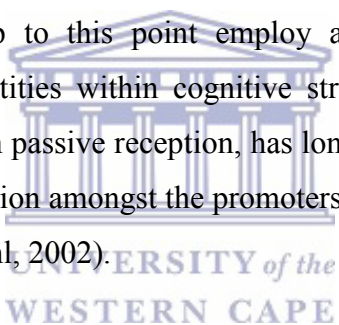
A socio-cultural view assumes the existence of an actively thinking individual while it focuses on social-level interactions. These two research viewpoints are best seen as complementary, not mutually exclusive (Cobb, 1994).

A broad, continuum is most appropriate, with cognitive viewpoints on one end flowing into socio-cultural viewpoints on the other (Greeno, 1997; Hedegaard, 1999). A socio-cultural viewpoint sees knowledge as strongly dependent upon the learner’s situation and culture (Bing &

Reddish, 2009). The aim is to understand the social setting as a whole, which includes the space the student occupies.

Along this continuum of research this study treats classroom interaction as a dynamic process where time is considered as a major parameter in the teaching and learning processes. Each action in the classroom has its own meaning within the whole context and history shared between the participants (Badreddine, 2009). In line with a socio-cultural perspective, it seems clear that as social beings students cannot learn effectively in isolation. This is why the Dialogical Argumentation Instructional Model (DAIM) lends itself well to a socio-cultural paradigm. It helps to show how students think and learn in communal activities. A more full discussion on this point will be presented in the next chapter.

Most of the studies reviewed up to this point employ a constructivist perspective where conceptions are seen as stable entities within cognitive structures or frameworks. An active engagement in learning, rather than passive reception, has long been promoted as stimulation for cognitive development and motivation amongst the promoters of constructivist views on learning (Bigge & Shermis, 2004; Krathwohl, 2002).



Another researcher with an interest in constructivist views on learning is Sherri (1995), who examines the effects of a constructivist learning environment on student cognition of basic mechanics and attitudes towards science. Sherri sets out to compare these effects with those of a traditional lecture course. His findings show that even though there were no significant differences between the two groups, qualitatively students reported that they had enjoyed the constructivist strategies: instructor interaction, hands-on activities and application to everyday life.

While such studies focus on the positive effects of constructivism, critics of the constructivist approach to learning can rightly maintain that constructivism does not have a monopoly on every aspect of learning. They cite the construction of knowledge by way of example. Good, Wandersee and St.Julien (1993) contend that though the term construction is attractive to educators, the idea of “knowledge construction” may actually be misleading. They urge

educators to exercise caution because our view of how the mind works is continually being revised. They advise that the best strategy may be to reserve judgment about constructivism while monitoring how it compares with new theories of learning and the findings of cognitive science.

This literature review captures some of the challenges students and teachers face in learning science through argumentation and other instructional approaches. But, despite the relevance of these studies some of their findings emerge from teaching and learning environments which are different from the South African context where the present study is located. Nonetheless, some results from the studies allude to scaffolding argumentation skills among students, pre-service teachers and teachers. With the exception of the works of (Diwu & Ogunniyi, 2012; Lubben et al., 2010; Ogunniyi, 1997, 2004, 2007a & b, 2008, 2009, 2011; Ogunniyi & Hewson, 2008; Ramogoro & Ogunniyi, 2010; Scholtz et al., 2008), they do not inform the present study of the effect their findings will have on students in different contexts, such as the context of this study.

In addition, even though the few argumentation studies noted here were done in South Africa, their foci were not on pre-service teachers' use of dialogical argumentation as strategies for solving mathematical problems in physics. For this reason, I shall now turn to some studies done in the South African context alongside a few conducted elsewhere on challenges pre-service teachers and students face with problem-solving in physics.

2.14 Teachers and students still face challenges with math-in-physics problem-solving

Research in problem solving has shown that solving a problem involves several types of mental tasks (Bing & Redish, 2009) such as creating representations of the problem (Larkin & Reif, 1979), recalling knowledge relevant to solving the problem (Shin, Jonassen, & McGee, 2003), keeping track of the problem goal (Sherin, 2006), and monitoring whether the results obtained are consistent with other known information (Heller et al., 1992; Mualem & Eylon, 2010).

For a long time the aim of science teaching has tended towards quantitative evaluation: 'how much one has learnt' rather than 'how well one has learnt,' which speaks of the quality of learning. Based on my teaching experience in physics, chemistry and mathematics at high school

and at university level within the South African context, 'how much a student has learnt' has often been the central focus. Emphasis is given to finishing the syllabus of the subject and to the examination. This approach leaves many gaps in what is learnt.

A study done by Basson and Kriek (2012) entitled "*Are Grade 10-12 physical science teachers equipped to teach physics?*" exposes teachers' lack of subject content knowledge. This was found to be the case especially in the township and rural schools of three provinces in South Africa: Gauteng, North West and Western Cape. Their findings indicate that incompetence cannot be blamed on curriculum modification. The findings further reveal that most teachers tested could not perform simple conversions or apply contextual knowledge.

Other studies conducted in South Africa have shown both teachers and students have had common difficulties in solving mathematics and physics problems (Brijlall & Maharaj, 2015; Govender & Dega, 2016; Maharaj, 2014; Selvaratnam, 2011). They acknowledge the prevalence of anomalies in strategies students used to solve both mathematics and physics problems. Recently, Ndlovu and Brijlall (2016) guided by the Action, Process, Object and Schema (APOS) theory studied pre-service teachers' mental constructions of the determinant concept.

According to Maharaj (2014), APOS theory proposes that an individual has to have the appropriate mental structures relating to action, process, object and schema in order to make sense of the given mathematical concept. What this implies is that these mental structures have to be detected, and then learning activities which will be suitable for the development of those mental structures, ought to be designed to enhance the construction of those mental structures.

One of the major findings from Ndlovu and Brijlall's (2016) study reveals that in most cases the mental constructions made by pre-service teachers concur with the preliminary genetic decompositions, and that many pre-service teachers are operating at an action/process stage, with the exception of the few operating at an object stage. This means that although many of the pre-service teachers in their study seem to have encapsulated the process/action stage, the meaning of the concepts was not conceptually understood as most of them could not evaluate, and some failed to generalize the formula for evaluation.

Studies in other countries have found that students do struggle with solving mathematical problems in physics. For example, Jewett (2008) studied students' confusion in solving mathematical problems in an introductory physics course. Junkins (2007) found that students involved in his study demonstrated inabilities to connect math-in-science knowledge during problem-solving. This problem is not new, which is why I deemed it necessary to look at both old and new studies in the area of my study.

The researchers, Reif and Allen (1992) found these students had deficiencies in interpreting the numerical answer they obtained in a given problem; they also showed a deficit in the area of knowledge.

According to Dolin (2002) it is important in physics education that students' mathematical modelling competency is developed. Based on Roth's contribution(1995), he has suggested, that physics appears difficult as it requires students to deal with interchanging multiple forms of representation as conceptual, mathematical, graphical, experimental and pictorial representations.

In addition to the foregoing studies, Sabella and Redish (2007) assert that because physics problems are typically quantitative, focusing on finding appropriate formulae and manipulating the equations to solve for a numerical value is indeed one aspect of physics that requires proficiency for competent problem solving.

Thus these studies all show that most students need some experience in mathematics prior to studying physics since mathematical reasoning and thinking accompany procedural fluency in physics problem solving (Bing & Redish, 2009; Redish, 2005). Junkins (2007) argues that mathematics is the language we use to communicate science, and science classes often necessitate the application of mathematics and vice versa. It was Vygotsky (1978) who put it simply when he stated that in conceptual development, language as a vehicle of communication in the hand of the knowing adult plays a significant role.

2.15 Language perspectives in learning physics as applied in the study

Because the medium of instruction is English (for physical science I-IV) at the institution where this study was conducted, another aspect this study endeavours to examine is the role that language plays in didactic situations. Many studies – such as (Ogunniyi, 1996; Nkopodi & Rutherford, 1993; Rollnick & Rutherford, 1996) – have examined the effect of language on the learning of science. Results indicate that the language of instruction is definitely a barrier in the learning of science – especially for those who receive science instruction in English but for whom English is their second or third language.

The research participants involved in my study are English second- language speakers who receive physical science instruction – physics and chemistry– in English. There are many related concepts in science which are given different names in English. However, in some of the African languages spoken in South Africa, the same word is used for different concepts (Moji & Grayson, 1996).

For example, Moji and Grayson (1996) investigated the effect on African students' learning of physics by using a single term in the mother tongue for several related but different physics terms in English. They suggest that this limited nomenclature of physics concepts leads to misconceptions and poor conceptual translation which could explain the general poor performance of African students in physics. The uniqueness of knowledge produced by an individual research participant is leveraged by the society in which all research participants live.

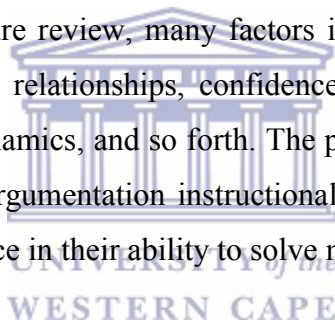
Adding to these studies, Garrick (1999) observes that there is no knowable social reality beyond “the signs of language, image and discourse” (p. 152). In his view, the knowledge an individual possesses is not uniquely in the custody of that individual because it is derived from the society in which the individual lives. Similarly, Bencze (2005, p. 1) argues:

While many theorists emphasize each person's right and tendency to construct unique meanings, many people also believe that these are not completely unique. Simply put, because we share common languages and conduct much of our thought through language and other communal symbols, many agreed that

knowledge is socially constructed, even while an individual is thinking. In a sense an individual's thought is never his or her own.

According to this excerpt, both uniqueness and commonality of individual constructs are to be expected. The uniqueness springs from the unique experiences of individuals, while the commonality originates in the culture and language of the society in which the individual lives. Quantitative methods can hence be used to assess the commonality of individual constructs in a population while qualitative methods can be used to probe for in-depth understanding of individual constructs. In the current study, all the PSAT items are expected to be tested in English, the medium of instruction at the university. Also, pre-service teachers are expected to use English language in all writing and communication pertaining to the study.

As we have seen from the literature review, many factors influence human thought, including past experiences, emotions, social relationships, confidence, available tools, and facility with prerequisite knowledge, power dynamics, and so forth. The purpose of this study is to determine the effectiveness of a dialogical argumentation instructional model. This entails assessing first year pre-service teachers' confidence in their ability to solve mathematical problems in physics.



2.16 Self - Efficacy

This section encompasses the second research question posed in Chapter 1. It explores how effective the DAIM is in enhancing pre-service science teachers' ability and sense of self-efficacy to solve mathematical problems in physics. This requires an outline of what self-efficacy implies and how it can be applied in this study as its protocols for measurement and analysis are pivotal to knowledge enrichment.

I am guided by Bandura's definition of self-efficacy, hence my operational definition. According to Bandura (1982), self-efficacy is the judgments individuals make about their competence to perform a defined task. For instance, a physics teacher may have very low self-efficacy pertaining to cycling, yet may decide on reflection that this is satisfactory and that it does not diminish his or her overall evaluation and feelings about the self. Various studies have shown

increasing empirical attention on self-efficacy; at the forefront are the works of (Bandura, 1986, 1994, 1997, 2006; Britner & Pajares, 2006; Gist & Mitchell, 1992; Wlodkowski, 2008).

In keeping with Bandura’s view, self-efficacy is concerned more with the ease, fluency, confidence and facility demonstrated by an individual in performing a given task. Self-esteem is a much broader concept in that it deals with a person’s self-image or sense of self. It also embraces a sense of identity and often includes self-efficacy. Perceptions of self-efficacy may be influenced by differences in personality, motivation, and the task itself (Bandura, 1994). Figure 2.2 presents a simplified view of the process by which self-efficacy is formed.

2.17 A model of self-efficacy-performance relations

The model as depicted in Figure 2.2 represents an adaptation of a self-efficacy construct. Bandura (1982) suggests that four categories of experience are used in the development of self-efficacy: (1) enactive mastery (personal attainments), (2) vicarious experience (modeling), (3) verbal persuasion, and (4) physiological arousal (for example, anxiety). Although these experiences influence perceptions of efficacy, it is the individual's cognitive appraisal and integration of these experiences that ultimately determine self-efficacy (Gist & Mitchell, 1992).

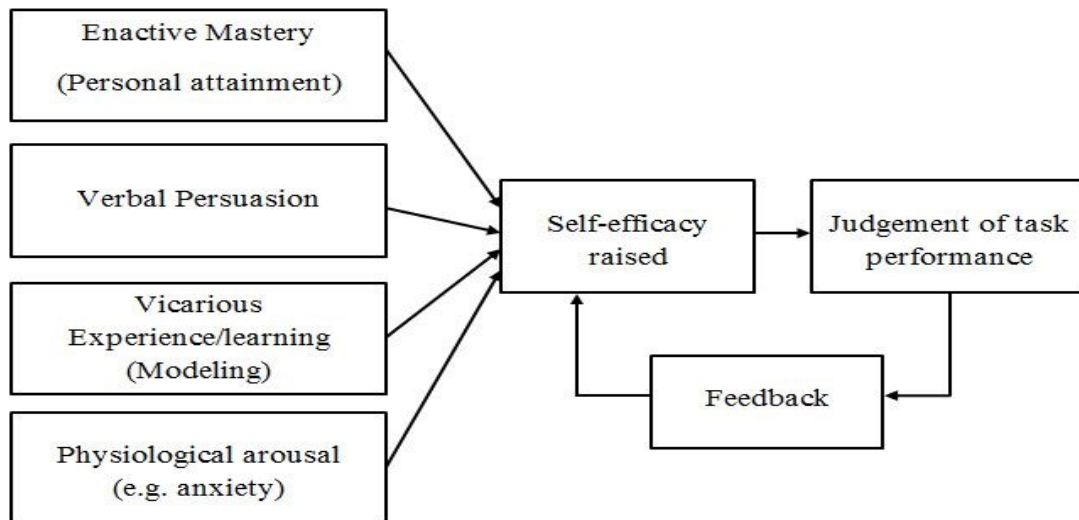


Figure 2.2 Diagrammatic representation of a modified self-efficacy performance relation

Enactive mastery (personal attainment) refers to the personal importance of doing well or succeeding in an activity. It could be the importance of attaining a cognitive goal (like creating something new) or attaining an affective goal (Bandura, 1994). It also includes the importance of doing well in an activity and so becoming approving or disapproving of one's self-schema (information about the self-based on previous and current experiences).

Verbal persuasion as applied in the current study refers to oral encouragement and the support one receives from significant others, for instance, in the case of a pre-service teacher. These 'significant others' could be peers or friends of the pre-service teachers, science lectures or family members who tell the pre-service teacher that s/he has the capability to successfully perform a given task or activity required of him or her. This factor is referred to elsewhere as 'social persuasion' (Bandura, 1994).

Vicarious learning, or experience, refers to influences arising from seeing others engage in an activity or a defined task in which they participate successfully. Role models in a DAIM group setting illustrate this dynamic. In view of the latter, Bandura (1994) argues that watching people or fellow students similar to oneself succeed through sustained effort raises one's belief that one too can succeed at a given task. Such role models who influence another's capacity to succeed is what Bandura (1994) calls 'social models'.

Physiological arousal refers to the actual trial or doing of the task. If, on the one hand, an individual engages in an activity or defined task and performs well, then the individual is motivated and is likely to decide to perform such an activity in future (Pajares, 2002). If, on the other hand, an individual performs poorly at a given task, this may lead to that individual's unwillingness to participate in such activity in future. Thus I am of the opinion that the latter is not always the case, because different individuals would react differently to their poor performance. Individual subjectivity in handling poor performance varies.

For example, various factors may be responsible for different individual reactions following poor performance. An individual's enculturation, upbringing and internalized values will determine

whether that individual, who may have performed very poorly, will participate in the same activity in future.

For instance, in many African countries such as Nigeria, it is part of their enculturation and internalized values not to give up when faced with their own poor performance. This is already taught at school. So the possibility that they will participate in the same activity in future after they had previously performed poorly is enshrined in the motivation they draw from their enculturation and internalized values.

Judgement of task performance refers to the inferences about what it takes to perform at various levels (Gist & Mitchell, 1992). It is most explicit when the task is fairly novel or when it has only been observed. For example, a pre-service teacher who makes a claim that s/he will perform well in mathematical problems in physics mechanics may consider the extent to which his or her mathematical abilities have enabled him or her to perform well in the past and how much time was needed to do so. In other words when the task has been performed personally, and frequently in the past the individual is likely to rely more heavily on his or her interpretation of the causes of previous performance levels. This is in line with problem or task recognition which was discussed earlier.

Apart from the influences that an individual receives towards performing a task or participating in a group activity (as in the case of DAIM), Saks (1995) explains that additional mastery experiences and supportive feedback ought to be included as part of a transfer intervention. Receiving immediate feedback has been found to raise self-efficacy. This has also been linked to physiological arousal, for example, anxiety, or motivation to persist with an activity (Pintrich & Schunk, 1996).

Much has been written about self-efficacy in the extant literature, regarding learning transfer outcomes. In this study self-efficacy development methods are used to enhance competency in the performance of tasks. To this end the four categories of experience suggested by Bandura (1982) are applied, with a focus on learning transfer from individual to small group as put forward in the DAIM settings.

2.18 Summary

In this chapter I have reviewed both theoretical and practical issues related to dialogical argumentation, which is the focus of my study. This review of the relevant literature attempts to show that, despite the studies that have been carried out on students, teachers and pre-service teachers, there is still a lot to discover about the nature of the argumentation strategies that pre-service science teachers use to solve mathematical problems in physics, and their sense of self-efficacy in doing so in a classroom context.

Science educators have found that students' knowledge of physics has been organized into naïve theories that are robust and coherent. This is especially true in mechanics where everyone has everyday experience of forces and motion, (Caramaza, McCloskey, & Green, 1981; Hammer, 1996, 2000; McDermott, 1984, 1991). Occasionally students studying mechanics have produced responses to questions anchored by commonsensical notions.

For non-Western science students like the African science students who formed part of this study, the issue of mathematical competence is alarming. For example, a few studies done in South Africa have shown that students still have difficulties in dealing with basic mechanics (Governder & Dega, 2016; Governder, 2007; Nguyen & Meltzer, 2003).

In terms of theoretical and practical considerations, my study has drawn some inspiration from the CAT, TAP and a number of other studies in the extant literature. Also relevant to my study, is the Downing's (2007) Analytical Model (DAM) which proved to be a very useful tool for my data analysis. In addition I relied upon the construct of self-efficacy performance relations by Bandura (1982/2006). For my data analysis on pre-service teachers' ability to use the Dialogical Argumentation Instructional Model (DAIM), I considered CAT and DAM. This is because each of these frameworks is capable of supplementing any discrepancies that might be found in my data analysis. On this basis I shall extend the use of CAT and DAM as analytical tools in order to answer my first research question. For my second research question, I shall use the construct of self-efficacy determinants.

Chapter 3 describes the methodology employed in my attempt to find answers to the research questions raised in the first chapter.



CHAPTER THREE

METHODOLOGY

3.0 Introduction

In Chapter 2, I began with a brief theoretical justification for why I regard argumentation instruction as an effective way of facilitating discourse, particularly in a multicultural classroom. The aim of this chapter is to describe why I prefer the dialogical argumentation instructional model (DAIM) underpinned by the Toulmin Argumentation Pattern (TAP), the Contiguity Argumentation Theory (CAT), and the Downing Analytical Model (DAM) over the other argumentation instructional models in the extant literature.

This chapter chronicles the overall research method and includes its sample, design, the development of the instrument, collection of data, analysis of data and ethical considerations. The chapter provides a detailed account of the use of the research instruments including the process of establishing their validity and reliability. Also included in the chapter are the operational implications for the final analysis of my data. In this regard, the overall research method has unique procedures. It is hoped these will give the reader the opportunity to judge whether or not the inferences or conclusions drawn from the data are valid and reliable.

3.1 Sample

This study focuses on an analysis of pre-service teachers' ability to use a dialogical argumentation instructional model to solve mathematical problems in physics. In pursuance of this aim a purposive sample was used because it is based in an institution in which I work and where I encountered the problem which forms the central concern of the study (Freebody, 2003; Opie, 2004).

Cook and Campbell (1979) point out that purposive sampling is a useful way of collecting data if it is carefully constructed. They argue that the use of purposive sampling depends on the nature of the research question under investigation. According to Datallo (2010), purposive sampling can be used to achieve the following goals:

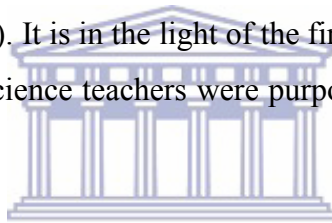
- to study a subset of the population (like teachers);

- to collect primary data for a pilot study that can be used to guide a larger study;
- to collect secondary data, which is to select a sample from an existing set of data; and
- to select a small subsample and closely examine typical and unusual or extreme elements.

3.1.1 Determining the sample

The Education and Social Sciences Faculty where the study was conducted comprises of General Education and Training (GET), which focuses on the Foundation Phase (FP: Grade R-3), Intermediate and Senior Phases (ISP: Grades 4-9) and Further Education and Training (FET: Grades 10-12). To be a physical science Grades 10-12 teacher, a student needs to take the FET courses with a science emphasis.

This study is situated in the FET context that prepares Grades 10-12 physical science teachers (secondary school science teachers). It is in the light of the first and second statements by Datallo (2010) that first year pre-service science teachers were purposively selected to participate in the study.



Sampling therefore, becomes context-bound within the selection of my students to whom I taught physics twice a week. In selecting the participants, I considered a number of factors that might have been hindering the pre-service teachers from performing optimally in math-in-physics problems. These included: (1) an inability to mobilise mathematical concepts needed to solve physics problems of mechanics; (2) an inability to provide justifiable arguments pertaining to a given problem and its possible solution; (3) an inability to use numerical answer(s) they had calculated at certain stages of a given problem, to solve follow-up problems; (4) an inability to interpret numerical answers to see whether the answer(s) they obtain make sense or not and (5) a tendency to grapple with the conceptual resource of mechanics.

Based on these considerations, the selection of the first year pre-service teachers was therefore necessary as a means of informing the present study. This pertains to whether the concerns revealed in the findings of my Masters' study about physics II and III pre-service teachers' performance in physics was related to their deficits in secondary school mathematics concepts needed to solve physics problems.

The present study was conducted at a historically black university in Cape Town, South Africa, the same university where I conducted my Master's study. The university is a multicultural institution.

The participants had enrolled at the university in the 2015 academic year to follow the science teacher training programme which is a four-year Bachelor of Education degree of FET specialization. All were registered as full-time students in the aforesaid faculty. As stated earlier, the participants are from a multicultural background. The institution produces a large number of qualified teachers yearly and hence is considered to provide the appropriate context for the study.

Earlier, while discussing the problem statement of the study, I provided justifiable explanation as to why the first year pre-service teachers were found most suitable for the study. Table 3.1 provides their demographical characteristics.

Table 3.1 Frequency of demographic Characteristics of the sample

| Valid | Frequency | Percent | Valid (%) | Cumulative (%) |
|--|-----------|---------|-----------|----------------|
| Item 1: Subject(s) elected with physical science: | | | | |
| Mathematics | 15 | 37.5 | 37.5 | 37.5 |
| Mathematical literacy | 18 | 45.0 | 45.0 | 82.5 |
| Other subject that is not mathematics or mathematical literacy | 7 | 17.5 | 17.5 | 100.0 |
| Item 2: Gender: | | | | |
| Male | 21 | 52.5 | 52.5 | 52.5 |
| Female | 19 | 47.5 | 47.5 | 100.0 |
| Item 3: Age: | | | | |
| 16 – 20 | 25 | 62.5 | 62.5 | 62.5 |
| 21 – 25 | 10 | 25.0 | 25.0 | 87.5 |
| 26 – 30 | 2 | 5.0 | 5.0 | 92.5 |
| 31 – 35 | 1 | 2.5 | 2.5 | 95.0 |
| 36 – 40 | 2 | 5.0 | 5.0 | 100.0 |
| Item 4: Indicate your cultural group: | | | | |
| Black African | 26 | 65.0 | 65.0 | 65.0 |
| Coloured | 9 | 22.5 | 22.5 | 87.5 |
| Indian | 1 | 2.5 | 2.5 | 90.0 |
| White | 4 | 10.0 | 10.0 | 100.0 |
| Item 5: Indicate your home language | | | | |
| Afrikaans | 14 | 35.0 | 35.0 | 35.0 |
| IsiXhosa | 22 | 55.0 | 55.0 | 90.0 |
| IsiZulu | 4 | 10.0 | 10.0 | 100.0 |
| Item 6: Indicate your disability status: | | | | |
| Sight | 2 | 5.0 | 5.0 | 5.0 |
| None | 38 | 95.0 | 95.0 | 100.0 |
| Item 7: Province where you matriculated: | | | | |
| Eastern Cape | 16 | 40.0 | 40.0 | 40.0 |
| Northern Cape | 6 | 15.0 | 15.0 | 55.0 |
| Gauteng | 1 | 2.5 | 2.5 | 57.5 |
| Western Cape | 17 | 42.5 | 42.5 | 100.0 |
| Item 8: Year of Matriculation: | | | | |

| | | | | |
|---|-----------|--------------|--------------|-------|
| 1995 – 1999 | 1 | 2.5 | 2.5 | 2.5 |
| 2000 – 2004 | 1 | 2.5 | 2.5 | 5.0 |
| 2005 – 2009 | 1 | 2.5 | 2.5 | 7.5 |
| 2010 – 2015 | 37 | 92.5 | 92.5 | 100.0 |
| Item 9: I did physical science from Grades 10-12 with: | | | | |
| Mathematics | 29 | 72.5 | 72.5 | 72.5 |
| Mathematical literacy | 11 | 27.5 | 27.5 | 100.0 |
| Item 10: In Grade 12 physical science (HG) I obtained Code: | | | | |
| 30 - 39% (Code 2) | 13 | 32.5 | 32.5 | 32.5 |
| 40 - 49% (Code 3) | 17 | 42.5 | 42.5 | 75.0 |
| 50 - 59% (Code 4) | 3 | 7.5 | 7.5 | 82.5 |
| 60 - 69% (Code 5) | 2 | 5.0 | 5.0 | 87.5 |
| 70 - 79% (Code 6) | 3 | 7.5 | 7.5 | 95.0 |
| 80 - 100%(Code 7) | 2 | 5.0 | 5.0 | 100.0 |
| Item 11: In Grade 12 mathematics /mathematical literacy (HG), I obtained Code: | | | | |
| 30 - 39% (Code 2) | 16 | 40.0 | 40.0 | 40.0 |
| 40 - 49% (Code 3) | 13 | 32.5 | 32.5 | 72.5 |
| 50 - 59% (Code 4) | 7 | 17.5 | 17.5 | 90.0 |
| 60 - 69% (Code 5) | 4 | 10.0 | 10.0 | 100.0 |
| Item 12: Where is your high school situated? | | | | |
| Urban area | 17 | 42.5 | 42.5 | 42.5 |
| Rural area | 18 | 45.0 | 45.0 | 87.5 |
| Pre-urban area | 5 | 12.5 | 12.5 | 100.0 |
| Total | 40 | 100.0 | 100.0 | |

3.2 Demographic Characteristics of the research participants

The demographics of the sample are as follows: Of the forty research participants who took part in the study, about thirty-eight percent (15) enrolled for physical science 1 with mathematics; forty-five percent (18) enrolled for physical science 1 with mathematical literacy; while eighteen percent (7) of the participants enrolled for physical science 1 with another subject that is not mathematics or mathematical literacy (see Table 3.1). Nearly fifty-three percent (21) of the research participants were males and forty-eight percent (19) were females. Sixty-three percent (25) of the participants were between the ages of 16 and 20, twenty-five (10) were between 21 and 25, twice five percent (2) were between the ages of 26 and 30 and 36 and 40 years respectively. Only three percent (1) was between the ages of 31 and 35.

The cultural (ethnic) groups in the study are representative of sixty-five percent (26) Black Africans, nearly twenty-three percent (9) of Coloureds, ten percent (4) of Whites and nearly three percent (1) of Indian (see Figure 3.1). Fifty-five percent of the participants speak IsiXhosa as home language, thirty-five percent (14) speak Afrikaans, and ten percent (4) were IsiZulu speakers. Two participants indicated they have minor sight problems, the rest of the participants indicated they have no sight or hearing problems at the time of the study.

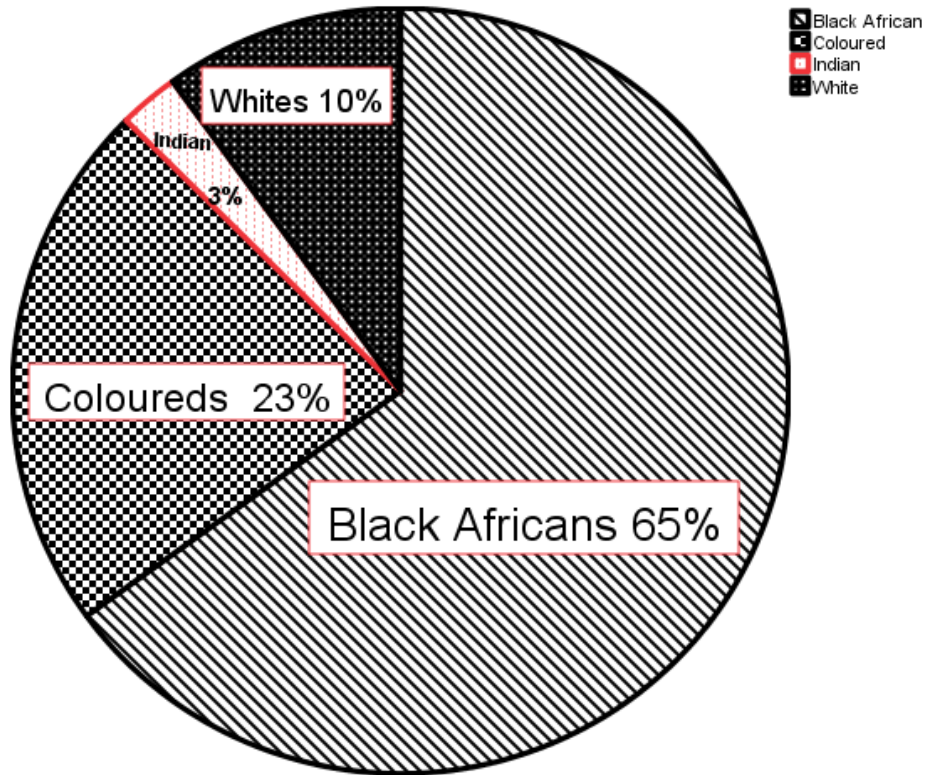


Figure 3.1 Ethnic group of research participants

As already pointed out, this study was conducted in the Western Cape Province, Cape Town, South Africa. There are 11 provinces in South Africa. Some are known to produce good Matric physical science results. Even though the institution where this study was conducted draws its students from across all the 11 provinces, the majority of the students come mostly from two of the provinces, namely: the Western Cape and the Eastern Cape.

Forty percent (16) of the participants completed their grade 12 high school attendance in the Eastern Cape; forty-two percent (17) were high school graduates from the Western Cape; fifteen percent (6) from high school in the Northern Cape, and only three-percent (1) from the Gauteng.

3.3 Research design: The case study approach

The choice of the research design for this study is based on the nature of the research questions and the nature of the phenomenon under scrutiny. In designing the study, I follow the case study methodology. Case study methodology is favoured in education as it can accommodate the messiness, uncertainty and complexity of studies of human behaviour. The classroom has all of

these characteristics, since teaching and learning is contextual (Freebody, 2003, p. 81).

According to Best and Kahn (1993), a case study examines a social unit as a whole where “the unit may be a person, a family, a social group, a social institution, or a community” (p.193). The same authors also define a case study as “a thorough observation of a group of people living together in a geographic location in a corporate way” (p.194).

Similarly, Cohen and Manion (1994) define a case study as an observation of “the characteristics of an individual unit – a child, a clique, a class, a school or a community” (p.106). In the present study, the social group, the unit, the case, was comprised of a group of first year pre-service teachers in a physics tertiary classroom. The method adopted allows me to investigate the case at some depth using a variety of data-gathering methods to produce evidence that leads to the understanding of the case and to answering the research questions.

3.3.1 *One group time series Design*

This design represents four phases of observation. In phase O_1 pre-service teachers responded to the PSAT instrument demonstrating their ability to solve mathematical problems in physics during a treatment condition. In Phase O_2 they demonstrated their ability to use the dialogical argumentation instructional model-DAIM as a strategic basis for solving mathematical problems in physics. Both phases were repeated a second time after a two-week school holiday, resulting in the following design $O_1 \quad X \quad O_2 \quad O_3 \quad X \quad O_4$. X is the argumentation-based instructional intervention (DAIM). This type of design also falls in the one group time series design. Data collection focused on forty pre-service teachers working in small groups. Pre-service teachers were observed for 8 lecture sessions, with intervals during each observation session. A total of 64 lecture sessions were observed within an interval of 6 months in which data was collected.

Figure 3.2 Four Phase Design $O_1 \quad X \quad O_2 \quad O_3 \quad X \quad O_4$

The four phase design (Figure 3.2) is regarded by many critics to be better than one pre-post-test design, that is, $O_1 \quad X \quad O_2$ (Cohen, Manion, & Morrison, 2001; Creswell, 2012).

At the very least the briefest consideration reveals inadequacy in the design of one pre-post-test design $O_1 - X - O_2$. For example, the question of how justified a researcher is in attributing the cause of $O_1 - O_2$ differences to the experimental treatment (X) is what makes the design weaker than the four phases design depicted in Figure 3.2 (Segool, Brinkman, & Carlson, 2007).

Still, one group time series design has its own general weaknesses. For example, extraneous sources of variation that could influence the differences between observations O_1 and O_2 in such design include: factors relating to the pre-service teachers, the educator (researcher), the classroom organization, the teaching and learning materials and their presentation, even the way the research participants were measured and the differences in their attitudes (Kratochwill & Stoiber, 2002).

Furthermore, additional weakness of the four phases design includes the absence of control which gives no room for generalization (Nagler, Rindskopf, & Shadish, 2008). But, since continuous assessment measures are used as a basis for drawing inferences about the effectiveness of intervention procedures, it was hoped that the design would assist me to gather as much data as possible emerging from the concerns that triggered the study into being.

3.4 Research procedures

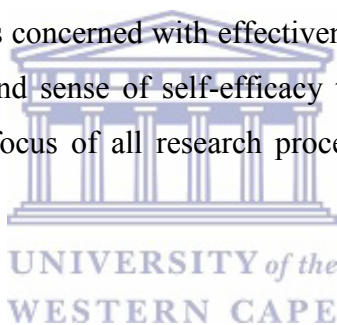
Generally the research procedure is the plan of how a study is to be conducted. The procedure for this particular study involves development, validation and piloting of all designed instruments (PSAT, IFDSE, GCEA and interview). It also includes implementation of the instructional model focusing on first year math-in-physics problems. This study was conducted over a period of one semester (6 months), a period of focused interaction and observation with first year pre-service science teachers.

The first year pre-service teachers were taught according to their lecture timetable. Usually the first year pre-service science teachers get two physics lectures per week. The average time per physics lecture at the institution is about 2 hours. This length of tuition time was considered suitable for the implementation of a DAIM-based lesson.

At the beginning of each month throughout the study, the first hour of the lecture was used for discussion and reflection on pre-service teachers' feedback from the previous 8 lectures. The results of the latter tests were then used to identify themes and other variables of interest which informed the subsequent interviews and observation schedules.

The next step was to identify the effect of the instructional strategy on the pre-service teachers with a focus on how to find out where changes were required. One possible way to achieve this was to identify themes in terms of the nature of argumentation strategies used by the pre-service science teachers in solving mathematical problems in physics. These observations took place before and after their having been exposed to a dialogical argumentation instructional model (DAIM) within small groups.

The second aspect of the study was concerned with effectiveness of the DAIM in enhancing pre-service science teachers' ability and sense of self-efficacy to solve mathematical problems in physics. These formed the main focus of all research procedures for the duration of the data collection.



3.5 Instrumentation:

3.5.1 Rationale for merging Quantitative and Qualitative methods

In research, the two most frequently used methods are quantitative and qualitative methods. Quantitative research involves the use of numerical values by which to analyze data while qualitative research focuses on the web of meanings integrating the processes by which people make sense of their worlds. The advantage of using both quantitative and qualitative methods is that they enhance the chances of gathering rich data.

Recognizing that all methods have limitations, the researcher felt that biases inherent in any single method could neutralize or cancel the biases of other methods. For example, the results from one method could help develop or inform the other method (Wilson et al., 1993; Creswell, 2012). Put another way, one method might be nestled within another and this may provide insight into different levels or units of analysis (Tashakkori & Teddlie, 1998). Or the methods could serve a larger, transformative purpose by pronging the need to change and advocate for

marginalized groups, such as women, or minority groups, or people with disabilities, or those who are poor.

Given the above rationale, the Physical Science Achievement Test (PSAT) items could provide quantitative information (numbers and figures) which are useful, but which might contain answers that are superficial in nature. This could then be overcome by supplementing the PSAT items with in-depth interviews conducted with a smaller sample group out of the 40 research participants.

3.5.2 Data consideration in case study

A plethora of research has shown that the use of multiple sources of data collection in a case study is influenced to a large extent by the nature of the research questions (Creswell, 1998; Stake, 1995; Yin, 2009). Nearly all the questionnaires used in the study contained both open and structured questions. For each question, a set of follow-up, probing questions were compiled from which I made a selection during the course of observations (O1 to O4).

While structured questionnaires are easy and useful in large-scale surveys, open-ended questions are more informative in case studies because they elicit deeper and richer responses from respondents (Freebody, 2003). It has often been said that no single instrument can capture the complete picture of what goes on in a single classroom. That is why I reiterate that the use of multiple instruments of data collection is common in case studies such as this one.

Moreover, classroom observation was used to extract data. Observations required little effort on the part of the participants since they happen as the activity is also happening (Darlington & Scott, 2002). However, the limitation in observations lies in what can be observed. In this regard, I could observe only the visible social phenomena and none of the cognitive and emotional processes of the participants, that is, why they do what they do and what exactly it means to them.

The study considered diverse sources of data, namely the Physical Science Achievement Test (PSAT), the Instrument For Determining Self Efficacy (IFDSE), Group Constructing and Evaluating Arguments (GCEA), classroom observations and semi-structured interviews.

These were used to corroborate one set of findings with another in the hope that two or more sets of findings would converge on a single proposition (Massey, 2004).

3.5.3 Development of instruments for the study

In general, a total of sixty-one items were developed (Appendix C) and used for data collection. Out of the sixty-one items, twelve content-based mechanics problems, (1.6-7.6.4, of Appendix C) sought to identify what types of argumentation strategies the pre-service science teachers use in solving mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM).

The rest of the forty-nine items sought to establish how the pre-service teachers constructed, wrote and evaluated the nature of arguments as strategies whilst solving math-in-physics problems. The PSAT items were enriched with items that could counter the five factors I highlighted earlier and that form the impetus for the study. All sixty-one PSAT items aimed at enunciating possible arguments, with twelve of them simply focusing on problem solving.

3.5.4 Considering Language while developing instruments

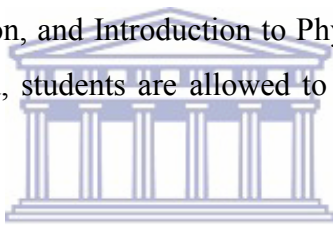
According to Duschl et al. (1999), the language of science is a discourse that critically examines and evaluates the numerous, and at times iterative, transformations of evidence into explanations. Language plays a significant role in learning. A valuable insight gained from the reviewed literature was that the language of instruction be kept as simple as possible.

This understanding helped me in my design of the instruments considering that English language is not the research participants' mother tongue. This is of primary consideration in the development of research instruments. It was hoped that this would enable me to understand the nature of the underlying math-in-physics conceptions in an argumentation context (DAIM). It was not concerned with becoming distracted by the pre-service teachers' paucity in English.

3.5.5 Data sources: *Physics mechanics I*

Physics 1 mechanics comprises a formal introduction to 2D-motions for education students for example, vectors, horizontal and vertical components, Newton's laws, forces and acceleration. It is usually taken in the first or second semester of the first year at the University. While most of these pre-service teachers have had a passing exposure to mechanics concepts in their earlier physics classes at secondary school, this class usually marks their first encounter with the full mathematical machinery concerned with solving 2D-motions. Some of these problems involve understanding and applications of trigonometric equations, formal linear algebra, and fractional equations leading to multiple equations that need to be solved simultaneously.

In terms of data sources, no standard textbook is in use for the physics 1 course at the Faculty of the University under study. Normally the lecturer uses Giancoli, *Physics*, 6th edition, *Fundamentals of Physics*, 8th edition, and *Introduction to Physics*, 9th edition textbooks for their lecture preparations. In this regard, students are allowed to use any physics textbooks of their choice.



Chapters of mechanics (2D-mentions) make up the usual content in which this study is interested. The major topics were chosen to align with the critical mathematical concepts. 2D mechanics was a primary focus, both in the abstract and in the context of mathematical content leveraged in the problems. Also, the topics covered in physics mechanics 1 tend to shift from year to year.

Based upon these considerations, nearly all the items were extracted from the aforementioned physics textbooks. In developing the PSAT instrument, I decided that all the items be based on conflict, and that the format of response be in form of argument and discussion. In this way, conceptions and misconceptions of Newtonian concepts held by pre-service teachers would be made explicit.

The second instrument is based on pre-service teachers' sense of self-efficacy, that is, the Instrument For Determining Self Efficacy (IFDSE). In developing this instrument I was guided by Bandura (2006) in two crucial ways. In the first part of the instrument, I provided a rating

table containing item numbers of the twelve math-in-physics problems in which pre-service teachers rate their degree of confidence by recording a number from 0 to 100. The ratings range from *cannot do at all* (0 – 40), *moderately can do* (50) and *highly certain can do* (60 – 100). In the second part of the instrument the items conform to PSAT. With IFDSE, the pre-service teachers' self-efficacy was assessed.

The third, interview instrument was developed according to the DAIM. The instrument consists of two main questions with four sub-questions. Since the aim of the interview was to extract more information from the pre-service teachers about their experiences on the DAIM lecture-based and traditional lecture method, a confidence rating scale on effectiveness of the DAIM was included with the sole aim of gaining useful insights.

Lastly, this instrument was developed as an observation checklist for the Group Constructing and Evaluating Argument – GCEA. Its items constituted various characteristics of argumentation including useful suggestions gained from the reviewed literature. I extended this instrument to include elements of sound or positive arguments such as observing listening skills and features.. In my attempt to capture the quantity and quality of the nature of arguments used by different groups as well as other classroom characteristics, I made use of a video-camera mounted in the classroom.

3.6 Validity and Reliability

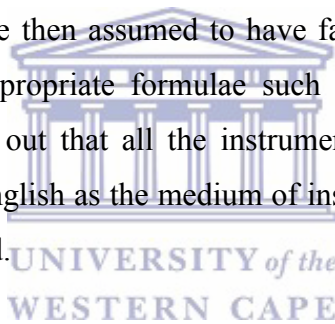
According to Silverman (2000) validity is another word for truth – the extent to which an account accurately represents the social phenomena to which it refers; while reliability is the degree of consistency with which instances are assigned to the same category by different observers or by the same observer on different occasions. Therefore, a valid instrument is one that measures what it is supposed to measure (Ogunniyi, 1992).

Guided by the views of these authors, I subjected the instruments of my study to various processes of validation such as submitting the instruments to science experts to rate the items in terms of linguistic clarity, conceptual quality, items construction, scientific accuracy of the items; the time allocated; the readability, the comprehensiveness.

The central aim of these precautions was to ensure that all aspects of math-in-physics content being tested would be adequately covered and that the suitability of the test would be appropriate for the particular level.

In line with these exercises, all the ratings were on a scale of 1 to 5. Any item scoring less than 3 was dropped or modified according to the comments of the raters. The final items with a score of 4 or 5 were then retained. Taken together, all the queries pointed out by reviewers of the instruments ensured that gaps were filled and discrepancies, inconsistencies and ambiguities were removed.

Moreover, the final revised instruments reflect both the input from persons with considerable knowledge in the specific content area, as well as the input of pre-service teachers (users of the instrument). The instruments were then assumed to have faced content and construct validity. The ratings were subjected to appropriate formulae such as the Spearman Rank Difference formula. Also it must be pointed out that all the instruments for the study – PSAT, IFDSE, GCEA, etc. – were presented in English as the medium of instruction is English for physics year 1 at the institution being researched.



In order to establish reliability, the PSAT items were rated on a scale of 1-5. The inter-rater reliability stood at 0.88 for the PSAT using the Spearman-Brown formula. Reliability coefficient of 0.80 was obtained using the split-half method. According to Fraenkel and Wallen (2008) a reliability coefficient of .70 for an instrument is considered reliable. Given the latter, the PSAT and IFDSE instruments were deemed valid and reliable for use in data collection.

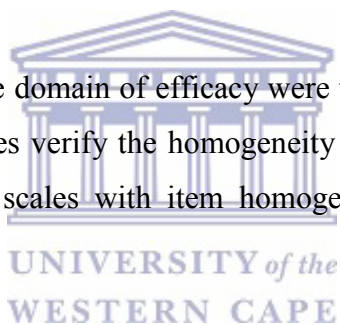
3.7 Piloting of the study

The study was piloted to check the suitability of the research instruments. This was done by testing the designed instruments among the non-participating students with similar characteristics to the research sample in order to get a feel of what is to be expected during the actual study, and to eliminate any ambiguities that might have gone undetected. Finally the results of the pilot test were subjected to appropriate formulae e.g. Kuder-Richardson formula 21. The reliability coefficient was very low (0.64). This could have been due to few items used which would have

limited the alpha level. The reliability coefficient was discarded and the number of items (math-in-physics problems) was increased from 7 to 15. When the items were again correlated for the actual study, the reliability coefficient stood at (0.80) and the inter-rater reliability stood 0.88 as already pointed out.

The IFDSE was initially piloted. Items that were ambiguous were rewritten and others were eliminated, especially where most pre-service teachers were checking the same response point. This is because such items do not differentiate among respondents. Items on which the vast majority of respondents check the maximum efficacy category lack sufficient difficulty, challenge, or impediments to distinguish levels of efficacy among respondents. To minimize such bias, the level of difficulty on IFDSE during the content validity was increased by raising the level of math-in-physics challenge. Examples of such items are 3.6, 4.6, and 6.6.

Further, the items tapping the same domain of efficacy were then correlated with each other and with the total score. Factor analyses verify the homogeneity of the items. Different domains of efficacy require different sets of scales with item homogeneity within each of the domain-relevant scales.



More details of results on self-efficacy are presented in Chapter 4.

3.8 The Dialogical Argumentation Instructional Model (DAIM)

In science education, dialogues form a very important means of externalizing one's thoughts and expressing agreement or disagreement with others' ideas. During the course of dialogical argumentation, individuals may realize their disagreement on scientific claims and grounds and this may lead to cognitive conflict. Although certain claims and grounds may be rebutted at each stage of the argumentation processes (individual task, small group task and whole class discussions), individuals and groups are encouraged to reach a consensus on claims and grounds pertaining to the science phenomena.

Consequently, dialogical argumentation may involve inductive, deductive and analogical logical reasoning strategies. Once cognitive harmonization has been attained, the individual could

achieve cognitive optima. In this regard, the levels of argumentation are determined at each stage of argumentation (individual, group and whole class) to ascertain whether the pre-service teachers are developing high-level argumentation skills. As various authors would argue, higher incidences of rebuttal of claims and grounds by individuals involved in the argumentation discourses could lead to the attainment of high levels of argumentation (Simon et al., 2006; Ogunniyi, 2007a & b).

Viewed from the foregoing perspective, dialogical argumentation enables learners, in their attempt to construct knowledge, to actively participate in class by making claims and using evidence to justify such claims, while other learners make counter-claims or rebuttals. In so doing, learners co-construct knowledge through discussion, collaboration and constructive arguments (Asterhan & Swartz, 2007; Erduran et al., 2004; Lubben et al., 2010; Osborne, 2010). Dialogical argumentation provides learners with the opportunity to express their views freely as well as to clear their doubts. Figure 3.3 shows an instructional strategy based on the use of the dialogical argumentation framework to engender dialogues amongst the pre-service science teachers.

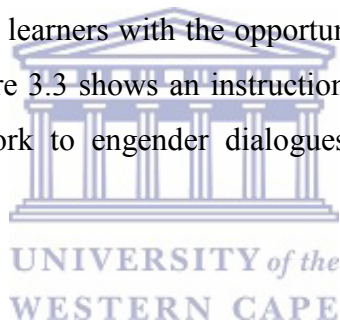




Figure 3.3 Pedagogical scheme for implementing dialogical argumentation instruction modified after Ogunniyi's (2009) -DAIM.

3.8.1 How the five stages of DAIM embrace self-efficacy and assessment of tasks

It is noteworthy that the main idea behind the successful use of DAIM is based on how effectively it is implemented. My second research question posed in the first chapter places an emphasis on determining the effectiveness of DAIM and pre-service teachers' sense of self-efficacy. From this consideration, Figure 3.3 shows how DAIM embraces self-efficacy and assessment of the task. Thus, I have added two simple uncluttered circles (6 and 7).

I will now provide an explanation to show the interrelatedness of each stage.

Stage 1: When an individual is confronted with a task (or given problem), a sort of “internal argument” or “conversation” ensues within him/her (at the microneuro-psychical level) where consciousness in an individual is assumed to be most active (Ogunniyi, 1997).

Stage 2: This is the stage where individual thinking or self-conversation (intra-argumentation) is brought into a social setting involving a small group of people arguing and discussing a given task (inter-argumentation).

Stage 3: At this stage group leaders or representatives present the decision reached by their respective group to the whole class for further debates and discussion.

Stage 4: At the fourth stage, the teacher (preferably facilitator) mediates the discussions. This is trans-argumentation.

Stage 5: At the fifth stage when stages 1 to 4 have been successful, an evolving cognitive activity is already in progress in the mind of the individual as arguments and counter arguments are presented.

Stage 6: An individual learner who makes a claim that he or she will perform well in a given task may consider the extent to which any of the 5 stages of DAIM had enabled him or her to feel at ease, and to express themselves with fluency and confidence.

Stage 7: Finally, an individual, a small group or the whole class is judged to determine whether or not a given task or set of tasks has been mastered than was the case before the intervention.

As already found elsewhere during the joint construction of a solution enacted through arguments, individual group members can request explanations and justifications from one another, in well-functioning groups. Students share their intellectual strategies as together they solve a given problem (Heller et al., 1992). Results from the latter study further suggested that better problem solutions emerged through collaboration than were achieved by individuals working alone. As has been noted by others (Ogunniyi, 2007a & b), successful implementation of DAIM is capable of achieving the latter objectives.

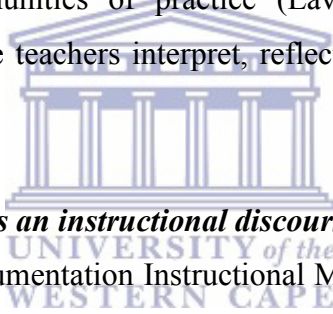
3.8.2 The central aim of DAIM

An anthropological perspective to learning focuses on a community of practice and what it means to learn as a function of being a part of a community (Lave, 1993). This shift in the unit of

analysis from the individual's context to the community (small group/whole class) context leads to a shift in focus from the learning of skills, to one in which developing an identity as a member of a community and becoming knowledgeably skillful are part of the same process which DAIM advocates.

According to Lave (1993) community provides the setting for the social interaction needed by learners to engage in dialogue with others to see various and diverse perspectives on any issue. In other words, community is the joining of practice with analysis and reflection to share tacit understandings and to create shared knowledge from the experiences among participants in a learning opportunity (Wenger, 1998).

Thus the goal of learning through DAIM, is to engage pre-service teachers in legitimate peripheral participation in communities of practice (Lave & Wenger, 1991). Through a community of practice, pre-service teachers interpret, reflect, and form meaning about a given task.



3.8.3 Implementation of DAIM as an instructional discourse

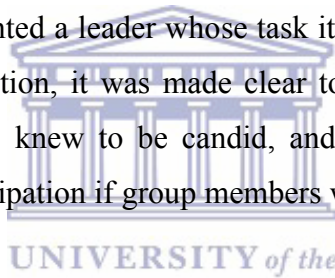
As stated earlier, a Dialogical Argumentation Instructional Model (DAIM) was employed as the pedagogic framework together with the Contiguity Argumentation Theory (CAT) and the Downing Analytical Model (DAM). Dialogic argumentation focuses on the interactions of individuals or groups attempting to convince one another of the acceptability and validity of alternative ideas.

Through dialogic argumentation students “articulate reasons for supporting a particular claim, attempt to persuade or convince their peers, express doubts, ask questions, relate alternate views, and point out what is not known” (Driver et al., 2000, p. 291). The use of CAT and DAM in the context of a science lesson has concentrated mainly on the description of small-group discussions among students. To advocate the use of CAT as both a theoretical and an analytical tool, I reiterate that CAT has been used in the tertiary context, and in particular in programmes aimed at training teachers in Africa (Ogunniyi, 2007a & b), which makes it a tool suitable for the present study.

Given the stages of DAIM and how they interplay during learning, it is easy to regard DAIM as a learning tool that enhances a cooperative learning environment. By a ‘Cooperative learning environment,’ I mean an environment where students practise using a strategy for solving problems in mixed-ability cooperative groups. It is only fitting then to say, DAIM implementation drew its inspiration from Contiguity Argumentation theory – CAT and Downing Analytical Model – DAM.

In what followed, the 40 first-year pre-service teachers were asked to form small groups, which randomized into 5 per group. Eight groups were formed in summation of 40, the whole class. It is therefore apposite to point out that the whole first year physics class participated in the study as the data collection conformed to their normal tuition times.

Next, each small group of 5 appointed a leader whose task it was to present or to lead the group discussion. For group leader selection, it was made clear to the pre-service teachers that they appoint a leader whom the group knew to be candid, and that this individual possessed the potential to encourage active participation if group members were not progressing.



In addition to each group leader’s roles, the leader took on time-management to ensure that the group made good use of the time given to them for presentation. Each group was provided with working materials (poster paper and whiteboard pens). While it was necessary for me to prompt tardy group(s) to respond to the arguments of other groups, beyond this, tardy group(s) were encouraged to think about issues emerging and principles underpinning them.

Equally, in a similar way, progressing group(s) were encouraged to explore consequences when arguments became narrowly focused.

Besides the implementation of DAIM, the question of what can or cannot be debated in classrooms remains open and is not easily answered nowadays. In this regard, efforts were made to ensure all arguments were non-intimidating, a necessary attunement for multicultural South African classrooms. A non-intimidating teaching and learning atmosphere was fostered as DAIM proceeded while data was collected.

3.9 Paucity in Students' math-in-physics reasoning: Concerns emerged after study was piloted

Prior to the commencement of the study, and as part of my preparation, I ensured that the PSAT items are relevant to the activities in the pre-service teachers' course guideline. In teaching math-in-physics content, I aimed at inculcating heuristic skills amongst my students by helping them to find ways in which they could acquire problem-solving skills.

In addition to this, pre-service teachers were guided in problem recognition, through strategic skills. This support is endorsed in the extant literature (Castells, Enciso, Cerveró, López, & Cabellos, 2007; Chin & Chia, 2004; Finkelstein, 2005; Heller, Keith, Anderson, 1992). But, in the case of my students, some of them found it challenging to acquire problem recognition skills. Without clearly recognizable basic problems, a composite problem becomes just one big problem and tends to be treated by less skilled problem solvers in the same way as basic problems when they attempt to arrive at solutions.

Numerous studies have shown that difficulty in problem recognition affects other cognitive factors such as the strategy employed in creating a solution procedure and how the procedure is represented (e.g. Heller et al., 1992; Kim & Pak, 2002; Larkin & Reif, 1979; Junkins, 2007; McDermott, 1993; Redish & Gupta, 2010).

In an effort to find a didactical approach to address the former, I re-grouped the students. This time I required the skilled individual and the less skilled individual problem solvers to concentrate on key words in the problem statement within their new group. This didactic approach – which I found in the reviewed literature – helped me to address the lack of problem recognition among my students.

While observing the pre-service teachers' progress in the latter didactical approach, I noted that the choice of a strategy appears to be related to the familiarity of a problem. For familiar problems, with which pre-service teachers have a lot of experience, skills well practiced can be encoded in long-term memory from whence they may be accessed and used to solve future problems. Having recognized a problem or its components, it is necessary to use some strategy to

obtain a solution path leading from the information given in the problem statement to the goal (the required answer).

To reinforce math-in-physics problem solving skills, I also taught the pre-service teachers in their small groups of 5 how to relate and represent a problem in diagrammatic form as a free-body diagram (FBD). This graphic representation captures the situation, how to identify key concepts of math-in-physics problems, and how to define the known and unknown quantities (data) needed for solving a particular problem, especially in the case of those questions that are deep rooted in mathematical structures or content. To illustrate this, I have included one of the math-in-physics concept questions that pre-service teachers struggled to grasp in the intervening teaching session prior to the observation O2.

3.10 Exploring Observation (O1) Data Collection and the Challenges experienced

Pre-instructional meetings took place between myself and the pre-service teachers at different times. It was agreed that since I teach the pre-service teachers physics twice a week a common place to orient them would be during the normal lecture. This idea was brilliant as it helped me to minimize any inconveniences. On more than two separate occasions I conducted orientations; on another occasion I requested that the pre-service teachers' lunch time be relaxed for further explanation to those students who had missed out on the first two inductions. In this time I explained the purpose and intention behind the PSAT, IFDSE, and GCEA instruments.

Having obtained permission from the pre-service teachers to conduct my study, I began my first observation (O1) data collection using the aforementioned instruments. During the O1 period I observed that many of the pre-service teachers were talking at each other, creating a noisy atmosphere. There was no evidence of talking and listening skills demonstrated by the pre-service teachers while debating and discussing given concepts. All the exercises seemed nearly worthless. This observation jolted me into becoming aware of what was at stake and the complexity of problems to address if the study was to achieve its purpose.

To deal with all the messiness and the pre-service teachers' lack of understanding of argumentation skills and practices, it was thought necessary to begin by helping them to unlearn

what they had learned. Misconceptions were found to be common given the manner in which they all responded to the instruments at observation (O1) level.

In order to address the aforementioned concerns, I began with an argumentation scaffolding programme. This was to prompt and prioritize the application of talking and listening skills in the pre-service teachers. It was not an easy exercise as many of the pre-service teachers were initially unfamiliar with such a learning style. I experienced countless difficulties in what appeared to be a never-ending struggle to inculcate talking and listening skills in the pre-service teachers. This was quite overwhelming. But with time, a sign of development (gradual adaptation) was observed among the pre-service teachers. This was encouraging given the keen interest demonstrated by the pre-service teachers to explore the new instructional method. After much struggle and critical brainstorming, a way to collect the data was found. This then was put to the test for the data collection at observation O2 level.

3.11 A description of math-in-physics mechanics problems taught & examined

In terms of complexity, quantitative problems in math-in-physics are of different kinds. First there are basic problems to solve which require a small number of steps, often only one or two. Then there are composite problems which require multi-step procedures and which often consist of a number of the basic math-in-physics problems linked together. The latter is the kind of math-in-physics problem that I shall address. Pre-service teachers were required to identify these component sub-problems and to devise a procedure by which to solve the whole problem. (Note in the problem context **N** means **Newton**, that is, unit of force F)

As can be seen in Figure 3.4, the problem statement of the question presented a context in which a toy train engine P, of mass 3kg, is connected by a string of negligible mass to a wagon Q of mass 2kg. A cable with negligible mass fastened to P pulls it with a force of 12N at an angle of 60° with the horizontal. The toy train then moves over a wooden floor during which the wagon Q experiences a frictional force of 1.0 N whereas the 3kg engine P has a coefficient friction of 0.1. It follows that the question required two separate free-body diagrams with labels, showing all the horizontal forces acting on P and Q.

In response to the latter question, free-body diagrams drawn by different groups of pre-service teachers fell short of what Mayer (1992) calls problem representation, in which a student builds a mental representation of the problem and illustrates it on a free-body-diagram. Worse still, a few groups could not correctly sketch a free-body diagram to represent the problem. Only five out of the eight participating groups of 40 pre-service teachers could sketch the free-body diagram correctly, which exhibited the notion they held.

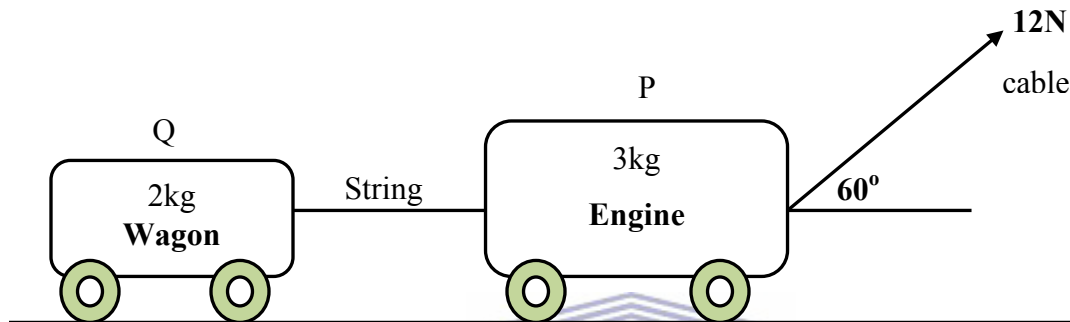


Figure 3.4 Diagram of a toy train engine P connected to wagon Q

The question that followed concerned problem-solving. The pre-service teachers were required to calculate the magnitude of the acceleration of the wagon-engine combination. Five groups out of eight failed to draw two separate FBDs for the engine P and wagon Q. They could not resolve the vertical and horizontal components to find the normal force (F_N) needed to compute the frictional force (f_p), a component that is part of the net force for the engine P.

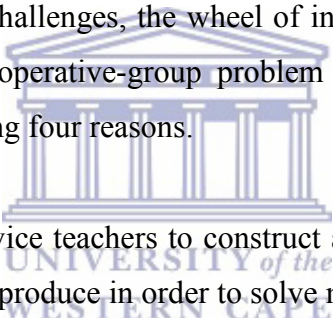
Furthermore, those who attempted the problem were only able to resolve it halfway as they argued that the gravitational force (F_g) is equal to the normal force (F_N). This assumption made by different groups of pre-service teachers could be found in the ambit of the object that is not accelerating up or down (that is, a case wherein the object is in a state of equilibrium), for only then would the engine P have ($F_N = F_g = W$). Others lacked a conceptual model on which to base their interpretations and calculations in respect of the tension force T_Q and T_P .

Other pre-service teachers were stuck in the ambit of what transpires between the net force of vertical and horizontal components. Two groups who nicknamed themselves as “go getters” and

“survivals” managed to correctly assemble all the forces required for the vertical and horizontal net forces, but failed to solve the problem correctly due to errors in mathematical computation of the components they derived.

The third question in the same problem required the pre-service teachers to calculate the magnitude of the tension force T in the string connecting P and Q . Again, the majority of the pre-service teachers failed to solve the problem. The few attempts which were made came from those who managed to draw the free body diagram correctly, and even so they did not arrive at the correct answer. Taken together, the solution they obtained for the acceleration of the wagon–engine combination was a pre-requisite for calculating the tension force T . As a result, both problems were solved incorrectly for all groups who attempted them.

In order to address the foregoing challenges, the wheel of intervention in teaching and learning was adjusted. This meant that cooperative-group problem solving as outlined in the DAIM setting was adopted for the following four reasons.

- 
- (1) It would enable pre-service teachers to construct and evaluate their argument for the kind of knowledge they produce in order to solve math-in-physics problems.
 - (2) It would enable pre-service teachers to observe each other constructing strategic thinking for problem recognition, constructing FBD, conceptualizing key concepts for math-in-physics like rules and/or principles, while extracting known and unknown quantities;
 - (3) It would facilitate mutual critique to clarify thinking about the concepts in question, and how those concepts and principles should be applied to a particular problem; and
 - (4) It would encourage members to request explanations and justifications from one another after reaching a concession through various substantive arguments.

3.12 Teaching and confronting mathematical problems in physics

Armed with critical lessons from the literature review the present study had to confront problems which could arise if mathematical models in physics are not properly addressed (Bing & Redish, 2009; Gupta & Elby, 2011; Kuo et al., 2013; Redish & Gupta, 2010). For example, many studies in science education have shown that most students need some mathematics experience prior to

studying physics since mathematics is the language we use to understand and communicate physics as well as other sciences (Hestenes, 2010; Martinez-Torregrosa et al., 2006; Redish, 2005).

Studies conducted in a tertiary classroom (similar to the present study) have this to say about tertiary physics students. Many tertiary physics students have been reported to have trouble expressing physics relationships algebraically, even after one semester of calculus (Junkins, 2007; Sabella & Redish, 2007). These authors believe that because physics problems are typically quantitative, focusing on finding appropriate formulae and manipulating the equations to solve for a numerical value, competence in this aspect is essential to proficiency in math-in-physics problem solving.

In terms of solving mathematical problems in physics such as the application of algebra and other algorithms in physics basic mechanics, I am concerned with something more than a sense of number and symbol. I wanted the pre-service teachers to develop a “sense of the mathematics,” an intuition for the structure of complex mathematical expressions that allows them to interpret and unpack these expressions, providing a capability for transforming equations and quickly recognizing errors.

With this in mind, I had to select the aspects of math-in-physics problems that could possibly generate arguments of mathematical content in physics. To do this, I resorted to the same problems that my students failed to solve and provided elucidatory steps on how such math-in-physics problems could be taught to physics students who are uncomfortable with mathematics. The following three questions were posed:

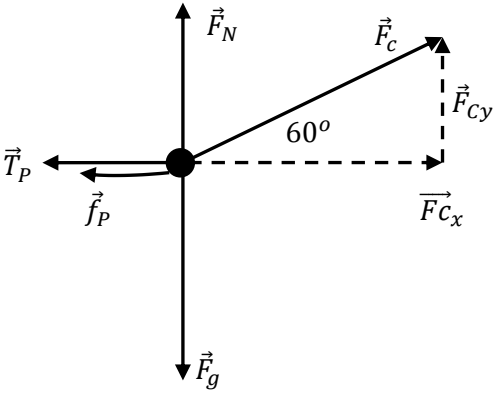
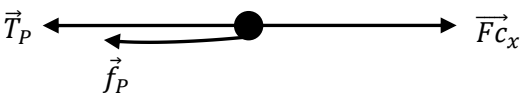
- (1) *Draw two separate free body diagrams with labels, showing the horizontal forces acting on P and Q .*
- (2) *Calculate the magnitude of the acceleration of the wagon-engine combination.*
- (3) *Calculate the magnitude of the tension T in the string connecting P and Q .*

To avoid taking us back and forth, I had decided to recap the problem statement from which the 3 questions were derived or posed, with the omission of Figure 3.4 (the original diagram of the question). To distinguish the problem statement from the actual discussion pertaining to it,

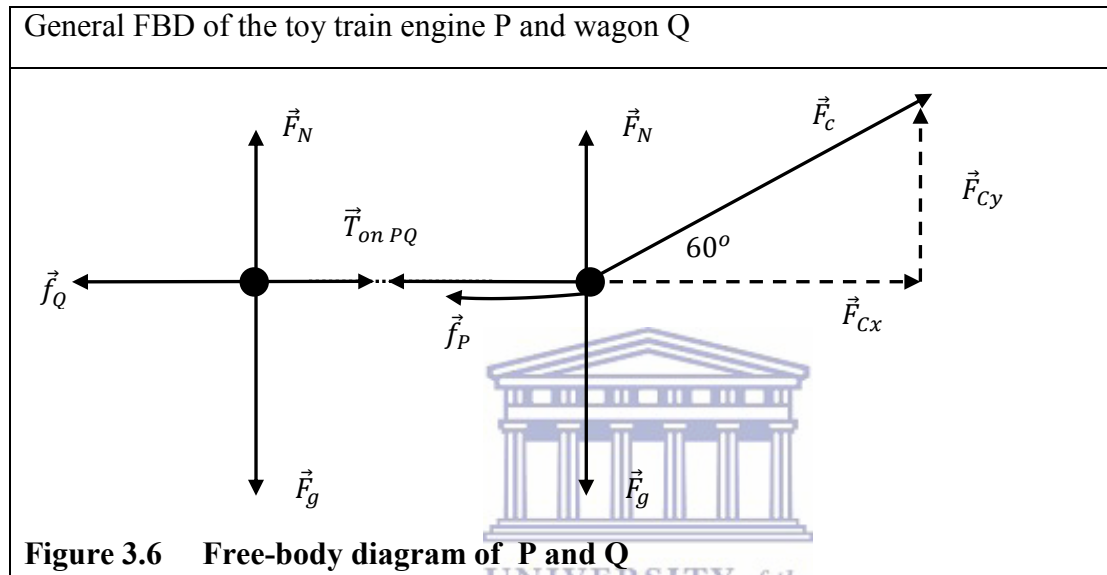
the problem statement was now posed in italics. The problem statement reads: *A toy train engine P, of mass 3kg, is connected by a string of negligible mass to a wagon Q of mass 2kg. A cable with negligible mass fastened to P pulls it with a force of 12N at an angle of 60° with the horizontal. The toy train then moves over a wooden floor during which the wagon Q experiences a frictional force of 1N whereas the 3kg engine P has a coefficient of friction of 0.1.*

3.12.1 *Overly procedural thinking towards math-in-physics problem-solving*

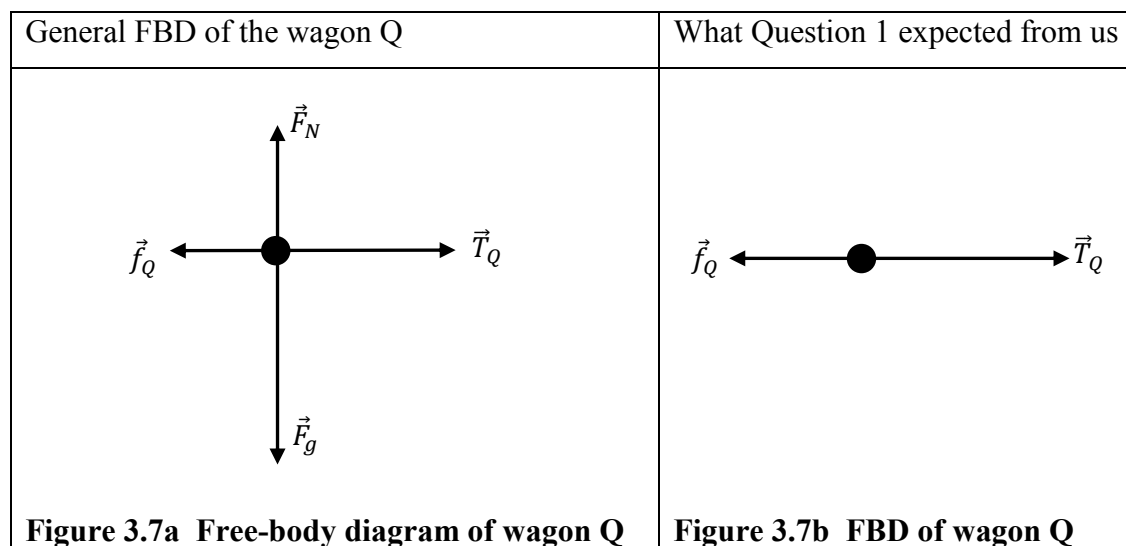
In practice, I streamlined my approach by not listing each step, as I prefer to provide the explanatory part of the two separate free-body diagrams. Starting with question 1, I explained: "We have two objects – engine P and wagon Q – so we need to draw a free-body diagram for each object. To draw them correctly, we must consider the forces on each object by itself, so that Newton's Second law can be applied to each. The cable exerts a force (F_C) on the toy train engine P. The toy train engine P exerts a force (T_p) (tension force) on the connecting string, and the string exerts an opposite but equal magnitude force (T_p) back on the toy train engine P (Newton's Third law). These horizontal forces on the toy train engine P are shown in Figures 3.5a and 3.5b, along with the force of gravity (F_g); the normal force exerted by the surface (F_N); the frictional force (f_p) and the force exerted by the cable (F_C).

| General FBD of the toy train engine P | What question 1 expected from us |
|---|--|
|  <p>Figure 3.5a Free-body diagram of toy train engine P</p> |  <p>Figure 3.5b FBD of toy train engine P</p> |

It might be tempting to say that the force the cable exerts, (F_C), acts not only on the toy train engine P. It doesn't. F_C acts only on the toy train engine P. It affects the wagon Q via the tension in the string, which acts on the wagon Q and accelerates it. Thus, we know that it is the tension that acts on both P and Q, taken together ($T_P = T_Q$). Put simply, Figure 3.5a is a generic view given to the latter while Figure 3.5b is what Question 1 wanted from us.



Next, I provide the free-body diagram of the wagon Q. Similarly, the forces acting on Q assume: force of gravity (F_g); the normal force exerted by the surface (F_N); the frictional force (f_Q) and the force exerted by the tension force (T_Q) as may be seen in Figures 3.7a and 3.7b.



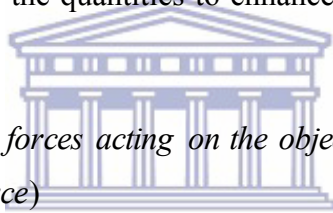
3.12.2 SOLUTION to Question 2: Calculate the magnitude of the acceleration of the wagon-engine combination.

From the two separate free-body diagrams (Figures 3.13b and 3.15b), we apply Newton's Second law, that is: $\sum F_x = ma_x$. We expect the motion to be horizontal, so we choose the x -axis horizontal and the y -axis vertical. We take the positive x -axis to the right and the positive y -axis to the upward direction. Following our choices we have:

$$\sum F_x = F_{c_x} - T_p - f_p = m_p a_p \dots\dots\dots[\text{toy train engine P}]$$

$$\sum F_x = T_Q - f_Q = m_Q a_Q \dots\dots\dots[\text{wagon Q}]$$

From the two equations, we define the quantities to enhance our problem recognition. They are listed as follows:



$\sum F_x \rightarrow$ Sum of all the individual forces acting on the object
(net force / resultant force)

$F_{c_x} \rightarrow$ horizontal component of the pull force by the cable F_c

$T_p \rightarrow$ Tension force exerted by the string on P

$T_Q \rightarrow$ Tension force exerted by the string on Q

$f_p \rightarrow$ frictional force acting on P (in opp. direction)

$f_Q \rightarrow$ frictional force acting on Q (in opp. direction)

$m_p \rightarrow$ mass of the toy train engine P

$a_p \rightarrow$ acceleration of the toy train engine P

$a_Q \rightarrow$ acceleration of the toy train engine Q

$\mu \rightarrow$ coefficient of frictional force of P

The toy train engine P and the wagon Q are connected, and if the string remains taut and doesn't stretch, then both the toy train engine P and wagon Q will have the same acceleration (a), put simply by the question, acceleration of the wagon-engine combination. Thus $a_p = a_Q = a$.

Next, we extract the known and unknown quantities as outlined in the description that follows. From Figure 3.4 of the toy train engine P, we are given ($m_p = 3\text{kg}$, $\theta = 60^\circ$, $\mu = 0.1$) while for

the wagon Q ($f_Q = 1.0\text{N}$). Thus we have extracted the known quantities. From the equation of the toy train engine P, we have the following unknown quantities: $F_{C_x} = ?$, $T_P = ?$, and $f_P = ?$ and for the wagon Q, ($T_Q = ?$). Since the angle θ and the force F_C are given, we can reconstruct Figure 3.5a, that is, the toy train engine; and by applying our mathematics skills of trigonometry, we can find the horizontal component (F_{C_x}). To do this, the pull force (F_C), which is 12N, has two components namely: the vertical F_{C_y} and horizontal F_{C_x} components (see Figure 3.8).

Figure 3.8 Free-body diagram for (F_{C_y} and F_{C_x}) components of P

From Figure 3.8:

$$F_{C_x} = F_C \cos \theta$$

[Horizontal component]

$$F_{C_y} = F_C \sin \theta$$

[Vertical component]

Next, we proceed to find frictional force (f_P) acting (in the opposite direction) of the toy train engine. Friction is a force that opposes motion it works in the opposite direction to the forward motion. The net force experienced by the wagon-engine is expected to decrease. Therefore, the acceleration will decrease according to Newton's Second Law ($F \propto a$).

In order to find the frictional force f_P we need first to find the normal force F_N (since $f_P \propto F_N$), from the following expression $f = \mu F_N$. Given that we took the positive y -axis to the upward direction, in the horizontal x -direction, both the normal force (F_N) and the force of gravity (F_g) have zero components. Because the toy train engine P is not moving vertically, ($F_{\text{net-}y} = 0$), normal force is not equal to the force of gravity ($F_N \neq F_g$), it equals the difference between the force of gravity and the vertical component of the pulling force ($F_N = F_g - F_{C_y}$).

Consequently, $F_g = W = mg$ and from Figure 3.8, using trig-ratios, we obtain $F_{C_y} = F_C \sin \theta$. However, the object does have acceleration ($a_P = a_Q = a$) in the horizontal direction. Horizontal net force equals the difference between the horizontal component of the pulling force and force of friction, as pointed out early.

Having generated all the known and unknown quantities, we now summon the two equations put forward. And solve the acceleration of the wagon-engine combination simultaneously.

$$F_C \cos 60^\circ - T_P - \mu(mg - F_C \sin 60^\circ) = m_P a \dots\dots\dots \text{[toy train engine P]}$$

$$T_Q - f_Q = m_Q a \dots\dots\dots \text{[wagon Q]}$$

$$12(\cos 60^\circ) - T_P - 0.1(3 \times 9.8 - 12 \sin 60^\circ) = 3a \dots\dots\dots \text{[toy train engine P]}$$

$$T_Q - 1 = 2a \dots\dots\dots \text{[wagon Q]}$$

$$4.099 - T_P = 3a$$

$$-1 + T_Q = 2a \text{ [since } T_P = T_Q, \text{ they cancelled each other]}$$

We add the two equations to give us:

$$a = \frac{3.099}{5} = 0.6198 \approx \mathbf{0.62m/s^2}$$

The acceleration of the wagon-engine combination is $\mathbf{0.62m/s^2}$ to the right. Next we want to find the tension force T. When a string pulls on an object (as in the case we are busy treating), the string is said to be under **tension**, and the force it exerts on the object is the tension (F_T). If the string has negligible mass as was the case in the problem statement we are dealing with, the force exerted at one end is transmitted undiminished to each adjacent piece of string along the entire length to the other end. Why? Because $\sum F = ma = 0$ for the string if the string's mass is zero ($m = 0$) or negligible no matter what acceleration (a) has. Hence the forces pulling on the string at its two ends must add up to zero (e.g. T_P and $-T_Q$).

It is noteworthy that flexible strings and cords can only pull. They cannot push because they bend. We can now calculate the tension force, which is the last question we are given. By using any of the equations we set up earlier, we solve for T_Q , hence we already know that $T_P = T_Q$ and that ($a = 0.62m/s^2$)

$$T_Q - f_Q = m_Q a \dots\dots\dots \text{[wagon Q]}$$

$$T_Q = m_Q a + f_Q$$

$$T_Q = T_P = (2 \times 0.62) + 1$$

$$T_Q = T_P = \mathbf{2.24N}$$

Thus the tension in the string is $T_Q = T_P = 2.24\text{N}$. And it is less than $F_C (= 12\text{N})$, as we expect, since T_P , acts to accelerate only (m_Q).

3.13 Training first year pre-service teachers how to construct, write, and evaluate arguments in DAIM setting

Through the observation (O1) instrument administered to the first year pre-service teachers, it was found that learning, in particular solving math-in-physics problems through argumentation is something new to them. Initially, pre-service teachers were unsure about how to participate in the argumentation process. Even though the pre-service teachers acknowledged that ‘argument’ is what they use in their everyday life, the application of the elements of argument as advocated in TAP by Toulmin, and the five categories of CAT by Ogunniyi were unfamiliar to them, and hence something new they were keen to explore.

Given the purpose of the study, the emphasis was placed on small group discussions of pre-service teachers, to produce justifiable arguments. Because the use of activities involving small group discussion was not established practice (Castells et al., 2007), all the pre-service teachers were provided with a detailed plan of how to construct, write, and evaluate arguments. As such, it was important to provide some ideas as starting points from which the pre-service teachers could construct, write, and evaluate their own or their group’s argument activities.

In order for pre-service teachers to be confident of fulfilling the demands of an existing first year physics module while taking on something that was new for them (argumentation discourse), it was envisaged that they would only be able to carry out small group activities with uncertain outcomes about once every 8 lectures (16 hours). To develop the pre-service teachers’ practice with argument, the six elements of TAP and the five categories of CAT were incorporated in the DAIM setting; with each tool complementing a synergistic relationship. This was done so that there would be an opportunity at the outset to observe and record how they use the nature of argumentation in strategies to solve math-in-physics problems.

The format of nurturing pre-service teachers' argumentation skills included advice on how they might engage in brainstorming ideas for and/ or against a particular physics concept. The instrument that lent itself well to the process was the observation checklist, that is, Group Constructing and Evaluating Argument (GCEA, Appendix E). Drawing on pre-service teachers' prior knowledge, and information collected from different physics sources already mentioned such as Giancoli, Physics, 6th edition, Fundamentals of Physics, 8th edition, and Introduction to Physics, 9th edition, I sought for consistency in the nature of argument strategies pre-service teachers adapted to solve math-in-physics problems.

Through the training sessions I also provided moral persuasion about how the pre-service teachers in training could use evidence to justify a position and how to use such evidence to enhance scientific argument by posing open questions. To achieve this, a set of arguing prompts were devised, designed to elicit justification, and were embedded in the PSAT instrument (Appendix C).

A number of Toulmin's (1958/2003) prompting questions were included, as listed here:

- “Why do you think that?”
- “What evidence supports your answer?”
- “Can you think of another argument for your view?”
- “What would you reply to your classmate to explain your position is right?”
- “Can you think of an argument against your view or other group’s view?” and
- “How do you know?”

To help the pre-service teachers understand what constitutes a valid argument the CAT categories and DAM levels of argument were introduced to help them clarify what was involved in the process of their thinking, and in the construction and evaluation of arguments.

Drawing on the extant literature about teaching students to write, construct and evaluate arguments (Berland & Reiser, 2009; Kuhn, 1991, 2010; Kuhn & Goh, 2005; Means & Voss, 1996), the pre-service teachers were also presented with writing frames to support the process of writing their constructed and evaluated arguments.

Providing stems of writing frames during argumentation training sessions has been used elsewhere in the extant literature by Simon et al. (2006). For the present study, stems of writing frames were incorporated in the PSAT instrument as, “My/Our argument is...”, “My/Our reasons are that...”, or “I/We would convince those (other group) who do not believe me/us by...” These stems were imbedded in the PSAT instrument for two purposes: (1) to provide prompts necessary to help the pre-service teachers construct a written argument; (2) to help me record notes of discussions, which reinforces the GCEA instrument.

The training sessions were devoted to support the pre-service teachers’ process of argumentation and the construction of arguments through both oral persuasion and written work (Duschl et al., 2007; Rivard & Straw, 2000). It was clear from the training sessions that pre-service teachers differed greatly in their perspectives on argument. Inevitably, each pre-service teacher adapted CAT and TAP elements in their own way, although all used the same basic idea.

3.14 Training Pre-service teachers on Talking and Listening skills during argumentation discourse

There is a considerable body of literature that argues for the promotion of discussion and argumentation as a means to developing critical thinking and group work skills (Duschl & Osborne, 2002; Erduran et al., 2004; Mitchell, 2010). This raises a key question concerning whether such skills may be acquired in a classroom situation where students do not recognize the pedagogical importance of talking and listening.

For example, if you are going to be able to argue, you have to be able to listen to know what the other people are saying. For some pre-service teachers this process is unfamiliar as they are not used to working discursively in groups when the predominant tertiary physics classroom strategies are more lecturer-directed. From the extant literature there is a close relationship between talking and listening, and skills acquired could foster individual reasoning (Mercer, Daves, Wegerif, & Sams, 2004).

For the present study, emphasis was placed on talking and listening skills because, in order for argumentation to take place, pre-service teachers have to be able to work in groups, talking and listening to each other and articulating their own ideas.

In pursuance of such a habit, I encouraged listening skills by asking participants what another had said. Also to avert participants simply talking at each other during the argumentation process, I kept on highlighting the value of listening skills by going beyond the common question-response-feedback pattern where educators would listen to one response, evaluate it, and move on to further questions.

Aside from argumentation skills, it is important that the pre-service teachers should acquire talking and listening skills since these skills are among those that teachers are expected to inculcate in the learners they teach. Noted at observation (O1) level, active listening was one of the skills many pre-service teachers did not exhibit in the argumentation context, but this skill, I believe to be an essential precursor to meaningful argumentation in small group discussion.

Prior to observation O2 I foregrounded the importance of encouraging active listening skills as a prerequisite to constructing arguments. To this end, it was critical that participants learn how to listen and talk, justify claims, and so on before they use arguments as strategies for solving math-in-physics problems.

3.15 Individual and Group PSAT activities in DAIM learning environment

This section explains how the pre-service teachers participated in individual-group activities during lessons on argumentation. Most of the PSAT activities took the form of debates, discussions and problem-solving in a cooperative learning environment according to the various learning stages of DAIM. The PSAT items encapsulate various tasks that allowed the pre-service teachers to interact and interrogate scientific concepts at individual, group and whole class levels.

For each debatable task the pre-service teachers were to come up with evidence to support their positions and also to come up with evidence to refute or counter other individuals' or groups'

knowledge claims. Aside from the selected math-in-physics problems assigned to the pre-service teachers to solve, the essence of the PSAT activities was to inculcate argumentation skills among the pre-service teachers as a way to addressing their difficulty of mathematical problems in physics mechanics. Since the knowledge that students produce is best viewed from a social constructivist perspective, having the pre-service teachers work in groups was thought necessary to enhance their knowledge construction and ability to solve math-in-physics problems.

In order to achieve this, it was important that the pre-service teachers learned how to argue effectively. To see whether this was feasible, another instrument GCEA was aimed at assessing the quality of argument the pre-service teachers produce in their respective groups. This was done by using their responses to improve their skills of argumentation, and by evaluating the quality of their knowledge claims, their counter claims, and their evidence. The pre-service teachers were asked to work in groups because working collaboratively in problem solving promotes scientific discourses; it promotes argumentation (Herrenkohl et al., 1999).

In addition, the pre-service teachers were also involved in individual and group activities during lessons in which I observed individual-to-group learning transfer of argumentation skills. In terms of assessment of small group-to-individual transfer of learning in the DAIM setting, the pre-service teachers completed twelve PSAT activities of Appendix C individually. Thereafter they did the same in a small group of 5 while individuals observed members of their group, and when this was completed, individuals went back to their seats, and the activities were again repeated, this time as individual activities. This generated fulfillment of the first two stages of DAIM consolidating its other stages – both its newly incorporated self-efficacy, and its assessment of tasks.

All group discussions were followed by a session where group arguments were shared with the whole class through group presentations followed by class discussions. Through listening to other participants' views, the listeners had an opportunity to reshape or even change their own original views. Thus the PSAT items were subjected to the same standard of physics 1 assessment for education students and all other incorporated tasks were typically structured into one unit per session, which allowed the pre-service teachers ample time to interact and interrogate, as suggested in the literature reviewed.

3.16 Data collection and its Procedure

Throughout the study, physics lectures for the first year pre-service teachers followed the course guideline. This meant that data collection was dynamic in nature in that a variety of data was collected from various maths-in-physics concepts in the process of being taught. In this way data was enriched by argumentation resources in the DAIM setting, unpredictable themes emerged which presented useful reflection in the context of the pre-service teachers' learning.

Some data like IFDSE and PSAT was collected at the beginning of the study when the pre-service teachers responded to the instruments. Audio-recordings and video-recordings that supported some aspects of the instruments especially (PSAT) were undertaken. To assess the nature of dialogic argumentation that the pre-service teachers used before being exposed to the DAIM (observation O1), analytical tools derived from CAT and DAM was used to analyze and inform the study of what the pre-service teachers' capabilities were at this point. Afterwards, the same argumentation tools (CAT and DAM) were applied to the classroom teaching and learning throughout the six-month duration of the study.

Again, whenever a new math-in-physics concept was introduced, observation of the pre-service teachers as they carried out argumentation tasks in the DAIM processes, were video-taped and transcribed. The video-recording was watched by me and lessons learned from it shaped the core of the interview questions for the interviewee. This idea was not fixed and when and where necessary, adjustments were made. For example, there was a need to station a video camera in some of the lectures and when that was not used a colleague of the researcher would stand in to guide students.

In collecting my data I was already aware of the advantages identified by Bay, Reys and Reys (1999) in providing students with an opportunity to try out activities using various forms of evidence. I provided the pre-service teachers with 'construct prompts' for deliberation. Examples of these are: 'state facts that provide a foundation to your answer', 'explain reasons that led to your solution (rules or principles) that connect the facts you stated', and so on. These 'construct prompts' as shown in the PSAT instrument, facilitated the important process of reflection in pre-service teachers' construction and evaluation of arguments. It was difficult to anticipate the extent to which I would do the same in a large group of whole classroom argumentation.

All data collected was treated according to the theoretical frameworks underpinning the study. The interview transcripts were analyzed and cross-checked with the participants to ensure validity of the conclusions. The participants were free to modify or correct what they felt was a misrepresentation of their intentions. Data from various sources (qualitative and quantitative) was synthesized to get a more holistic interpretation, or as a means of triangulating in order to obtain greater validity or credibility.

3.17 Procedure for determining Effectiveness of DAIM in the study

In line with the constructivist approach, I incorporated everyday science activities in the PSAT instrument (see Appendix C) for three socio-constructivists' reasons:

- to arouse pre-service teachers' interest in learning through their personal experiences;
- to enhance the pre-service teachers' stimuli and responses, and to reinforce active dialogic arguments;
- to motivate and challenge the pre-service teachers' thinking.

To achieve this, pre-service teachers were observed for 64 lecture sessions, with intervals (16 hours of 8 lecture sessions) during each observation (O1 to O4) consistent with the one group time series design. Following the design, pre-service teachers responded to the math-in-physics problems demonstrating their ability to use the DAIM as a strategic basis for solving math-in-physics problems in which data was collected.

In addition, a confidence rating scale on the effectiveness of the DAIM was used to collect data on the Likert Scale. All data collected from the commencement of the study until its end following the four phase design in the DAIM learning environment was used for data analysis. The aim here was to determine the effectiveness of the DAIM in enhancing pre-service teachers' ability to solve math-in-physics mechanical problems.

3.18 Tertiary Classroom Observation

In conducting a classroom observation, many important events cannot be observed directly so some inferred condition which helps us to interpret observable events in a parsimonious manner is necessary. This is because sometimes what seems obvious is not necessarily true. Parsimonious manner refers to a way in which a researcher remains close to his data rather than engaging in unbridled speculation (Creswell, 1998, 2012). In doing so the interpretation of data is that, all things being equal, the preferred explanation is the simplest or least complex.

Earlier on, I had used the notion ‘participant-observer’ to indicate a sense of inclusiveness. Freebody (2003) asserts that the participant-observer role involves some level of deception, that is, a degree of pretense by a researcher so that the participants are oblivious of their being observed. Put another way, the presence of a participant observer can affect the behaviour of participants in what is usually known as the Hawthorne effect (where participants behave in a certain way because they know that they are being observed).

This assertion is always the case especially when participants have to work with a ‘new face’, a facilitator or participant-observer, foreign to them (an outsider). It is easy then to assume that change in learning behaviour may not occur if the research participants have to work with an ‘old face’, that is, a facilitator or participant-observer they have known and are accustomed to working with. Familiarity may be seen by the participants as ‘business as usual.’ So with due consideration my participant-observer role was fully negotiated.

Both my students and I were aware of my role to observe them while they solve given mathematical problems in physics using argumentation. Clearly it is not possible for one to observe every aspect of a didactic nature in a classroom during tuition, especially within argumentation discourse. Therefore, a video camera mounted in the lecture room was used to record any observable attributes of students learning which I was unable to capture. More comprehensive detail of such points is presented in the next section entitled field notes.

3.19 Field notes and challenges faced in the study

As human beings, our minds tend to forget things quickly. In conducting a research study there are some things we can barely remember while being exposed to behaviours and thoughts about other humans, which is why Groenewald (2004) suggests that a researcher must make use of a process he calls ‘memoing,’ otherwise referred to as compiling field notes.

Field notes are considered to be a less obtrusive way of recording information during observations (Darlington & Scott, 2002; Denzin & Lincoln, 2011). The field notes were descriptive in nature as I reflected on each interview immediately after it took place. At times I would make notes during the interviews to keep the field notes fresh. As such I took ‘theoretical notes’ which according to Groenewald, 2004, p.15 is an attempt to derive meaning from the non-verbal cues that emanate from the interviews.

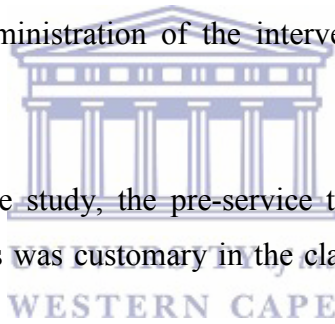
The notes provided greater detail and wider descriptions of settings, physical or social, as well as interpretive notes and follow-up questions. I recorded what I heard, saw, experienced and thought in the course of collecting data. In so doing I made what Groenewald (2004) calls observational notes (recording what happened) and theoretical notes (attaching meaning to what was observed) during the research process. This was a nigh impossible task though, as one person cannot do all things.

As I teach the first year pre-service teachers physics twice a week, I was not able to record everything that happened whilst teaching. Alternatively, it would have been ideal to recruit another person to observe and record the events of the lecture sessions as they occurred but I was not in a financial position to cover such expenses.

To address this shortcoming, I made use of the video camera mounted in the lecture room, to which I have already referred. Thus, the video camera captured all the lecture sessions and interaction. The recording was watched and transcribed for analysis. Consistent with this, I diligently watched the video and extracted data at the end of each lecture session. This I did for the following reasons:

- Allowing the videos to pile up for many or all the lectures pertaining to the study would have been too cumbersome.
- The video camera might have captured important elements that needed to be addressed before proceeding with the next lecture.
- The video camera might have recorded events that confirm other instruments such as GCEA, interviews, and so on.

Given these reasons, it was thought that one way of providing immediate feedback throughout the study was to watch recorded footage at the end of each lecture session. Events captured by the video camera could point at an impending pattern (good or bad) and can determine whether or not the inquiry needs to be reformulated or adjusted or redefined based on the observations being made. In this way interesting incidents like sudden changes in classroom interaction or new ways of approaching the administration of the intervention programme and instruments could be noted.



Prior to the commencement of the study, the pre-service teachers and I agreed to switch all mobile phones to 'silent mode,' as was customary in the classroom rules. This was maintained throughout the study.

3.20 Interviews

3.20.1 Preliminary interview happened during Pre-service teachers' exam revision

In terms of group formation, there were 8 small randomized groups, 5 per group of the 40 first year pre-service science teachers who took part in this study. One pre-service teacher was randomly selected from each of the 8 groups. As such, 8 pre-service teachers were chosen for the interview.

Since each interviewee was selected from a group, it was expected that each group's voice would be heard in all matters concerning their engagement in the study. Four hours of (two lecture sessions) for this study were used for one-on-one interviews of 8 pre-service teachers with the researcher.

The four hours were devoted to addressing the first research question using some sections of the PSAT. At the time of the interview the intervention programme (DAIM) in which the second research question featured was not yet revealed to the pre-service teachers. So the preliminary interview session was primarily made up of problem solving interviews where each selected pre-service teacher was asked to solve a particular problem at a whiteboard while vocalizing his/her thoughts.

The main problems themselves were preplanned, but the interviews were not scripted at any level of detail. As their work on the problems progressed, depending on what the pre-service teachers brought up, I would ask various sub-questions. The goal was rarely to get the pre-service teachers to arrive at the correct answer of a problem during the interview. An interview would usually begin with me explaining that I simply wanted to hear what the pre-service teacher had to say about these various problems.

Lessons learned from the preliminary interview exercise were important for the main interview, especially in relation to time management and the length of the PSAT content design. For example, a two and half hour session was devoted to addressing the first research question which deals with math-in-physics problem-solving. This extended to more than 55 minutes of additional time which was allocated to interviewees who requested clarification. Based on this experience, I prepared adequately (in terms of material resources and time management) for the second observation (O2) interview.

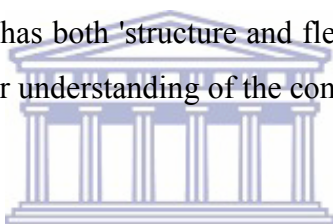
3.20.2 Main interview

Interviews are conversations between researchers and the respondents (in this case, the first year pre-service teachers), designed in order to obtain information from them, to follow up on ideas and to probe further or to validate other methods (Gorard & Taylor, 2004; Silverman, 2000). This interview protocol was designed according to the two research questions posed in Chapter 1. In the best of interview protocols, Patton (1990) clearly explains the circumstances under which interviews are suitable saying:

...we interview people to find out from them those things we cannot directly observe. We cannot observe feelings, thoughts, and intentions. We cannot observe behaviours that took place at some previous point in time. We cannot observe situations that preclude the presence of an observer. We cannot observe how people have organised the world and the meanings they attach to what goes on in the world. We have to ask people questions about those things (Patton, 1990, p.196).

Semi-structured interviews and discussions were conducted with the pre-service teachers following the same pattern as in the preliminary one. Eight pre-service teachers were randomly selected from the 8 groups of 40. Nearly two hours were used to capture data on the first research question, which involved selected mathematical problems on physics mechanics 1. Another one hour and a few undocumented minutes were used to capture data on the second research question, which focused on the intervention programme (the Dialogical Argumentation Instructional Model-DAIM), and the pre-service science teachers' sense of self-efficacy.

The aim of the interview, and discussion, was to seek further clarification of ideas the pre-service teachers would have raised in their earlier responses to the PSAT items which required reflective essays of their arguments. The semi-structured interviews present open-ended questions designed in such a way that I can probe and encourage the participants to explain and expand on their answers. In this way the interview has both 'structure and flexibility', which allowed me and the pre-service teachers to negotiate our understanding of the context and situation of the phenomena under consideration.



One open-ended question was designed to extract data specific to each of the research questions. The reason for an interview that relies on an open-ended questioning technique is that in such approach, the interview is held in a conversational manner. This allows participants to freely express themselves as they wish, instead of the researcher restricting the discussion to certain predetermined questions (Creswell, 2012). Also, an open-ended questioning technique would help me to determine the initial responses of the pre-service teachers.

For each open-ended question, a set of follow-up, probing questions were compiled from which I would select during the course of the interview itself (Appendix F). Precautions were taken to allow the pre-service teachers to talk freely without unnecessary restrictions. In order to achieve this, I made an effort to keep these interviewed pre-service teachers talking as continuously as possible, vocalizing their ideas as they tried to resolve whatever questions came up in real time.

Effective prodding was particular to each participant. Some pre-service teachers were simply more talkative and comfortable discussing the selected math-in-physics problems as well as the intervention programme (DAIM). If such a pre-service teacher was quiet for two minutes, a quick “What are you thinking about?” prod would typically make him/her start talking again.

Other pre-service teachers were either less comfortable with the selected math-in-physics problems or merely liked to quietly form their sentences more completely before they started to talk. Constantly prodding these pre-service teachers after every 1-2 silent minutes would be, at best, distracting and, at worst, belittling. I noted this, and exercised caution when dealing with pre-service teachers who showed signs of discomfort.

Moreover, being conscious of time allocated to each respondent, it was necessary to find ways to get them talking. Each individual interview’s dynamics, then, depended greatly on my impression of that particular pre-service teacher’s talkativeness and comfort levels.

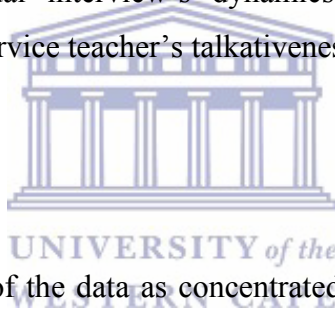
3.21 Data Analysis

3.21.1 Analytical Framework

This section presents an analysis of the data as concentrated on specific features. Chief among these is the extent to which pre-service teachers have used the nature of the dialogical argumentation instructional model as a strategic mobilizing tool when solving physics problems of mechanics that require mathematical concepts.

Various frameworks, schemes and tools can be found in the reviewed literature of Chapter 2 to assess the quality of arguments in science education. The most prominent ones are the works of the following authors: (Erduran et al. 2004; Naylor, Keogh & Downing, 2007; Ogunniyi, 2007a & b; Toulmin, 1958/2003). Some of these frameworks turned out to be inappropriate for my study for various reasons. These are as follows:

- The “one approach fits all” usually has limited explanatory and predictive outcomes because most of the elements of TAP in an all-purpose discourse may have little or no relevance to the domain of functioning, which in turn leaves much ambiguity about exactly what is being assessed (Erduran et al., 2004).



- Based on my experience in working with science and mathematics students at both basic and higher education levels, very often students' utterances in class are fragmented and overlapping. Science classrooms are sometimes filled with messiness, which makes it difficult to capture group dynamics, and chains of reasoning as groups construct and evaluate arguments pertaining to a given task.

About these considerations people differ in the areas in which they cultivate their argument and the levels to which they develop it even within their given pursuits. For example, an African science student (as in the case of the current study) who uses non-logical elements to foster his argument may see his insight disregarded in space (logic context) that diminishes (or silences) his worldview. Thus, he might feel isolated and be discouraged from carrying on with the dialogic argument.

Supplementing this, CAT caters for both logical and non-logical aspects of argument worth using to present fresh perspectives on how African science students use the nature of argument to solve mathematical problems in physics as opposed to having an analytical framework that caters only for monologues. In terms of an analytical consideration, CAT is unique because it arose from a series of intensive empirical investigations. It is based on argumentation discourse which takes into consideration the role of cognitive interplay towards enhancing conceptual change and development. Also, it is evident that CAT is universal in its application and has educational implications for teachers at all levels of education. Likewise, CAT is a handy analytical tool for interrogating classroom discourses.

Like CAT, the Downing analytical model (DAM) of argumentation recognizes students' arguments generated in small groups. In this study, DAM is primarily applicable in the in-the-moment patterns pre-service teachers employ in their speech and thought as they construct and communicate arguments. These in-the-moment argument constructions are often verbally incomplete. They often refer to a body of knowledge that the speaker (correctly or incorrectly) assumes s/he shares with the listener. These flow-of-conversation arguments sometimes have holes in them that are consciously or unconsciously overlooked. In short, my analytical framework is underpinned by CAT and DAM.

3.21.2 *Modification of analytical framework - DAM*

Initially, I proceeded to use the Downing (2007) analytical model (DAM) for analysing small group arguments and discussion, but during the analysis, I became dissatisfied. I found that using the Downing analytical model would not only lead to generalisation of the students' stances, but it will also yield certain discrepancies, as outlined here.

- (1) From the onset, it makes no room for students who are able or willing to enter into discussion, despite the importance of this in the teaching and learning situation. Level 1 argument according to Downing (2007) only recognises the negative attributes of students' discussion. In this study, I have decided to classify this 'negative attribute' as "level - 1" and the positive attribute as "level +1". For ease of reference, the modified analytical model recognises both positive and negative attributes as "level ± 1 ", whereby description of the positive attribute says "students are able or willing to enter into discussion" [level +1].
- (2) The first part of the level 2 argument, according to Downing, recognises when students make a claim to knowledge. In my study, I am not only interested in the claim to knowledge students make, but I am equally interested in whether the claim to knowledge is 'relevant or irrelevant' to the activity in question. In order to recognize the 'relevant and irrelevant' aspect to the claim to knowledge, I have classified the claim to knowledge which is "irrelevant" to an activity in question as "level - 2" and the "relevant" aspect as "level +2". This then facilitates the recognition of both versions of the claim to knowledge as "level ± 2 ".
- (3) At level 5, according to Downing, a positive attribute of students' responses is recognised; but when this is not the case, it is difficult to classify. For this reason, I refer to "no response from students to ideas from others in the group" as negative attribute [level-5]. This I do as a way to recognise what aspect of the students' discussion hinders rebuttal. Students responding to ideas from others will inevitably lead to more rebuttals and strengthen the quality of their arguments to solve mathematical problems in physics.

The latter is well enshrined in the literature for example (see Clark et al., 2007; Erduran et al., 2004; Kuhn, 1991). When this does not happen, one expects weak rebuttal and poor discussion.

In short, it was Erduran et al. (2004) who put it simply when they said the frequency of rebuttals can be used as a determining factor to judge the quality of an argument, so the greater the number of rebuttals, the higher the quality of that argument.

(4) The positive attribute of level 7 according to Downing was to be modified given the purpose of the study and its research question. It is thus pivotal that evaluating and making good sense of judgement with evidence are key skills one would expect from the pre-service teachers if they are to solve problems efficaciously. When this is not the case, that is, a negative attribute against positive attribute of Downing's level 7 argument, the study recognises such a case as "level - 7".

To summarise the modification after Downing's (2007) analytical model, the study has now recognised levels of arguments [1, 2, 5 and 7] in terms of positive and negative attributes [± 1 , ± 2 , ± 5 and ± 7]. The levels 3, 4 and 6 pose no challenges in analysis and therefore were used as Downing proposed them. *The modified version of DAM is depicted in Table 3.2.*

Table 3.2 Analytical model of argumentation modified after Downing (2007) for the study

| Level | Description of Arguments |
|---------|---|
| ± 1 | Students are unable or unwilling to enter into discussion |
| ± 2 | Students make a claim to knowledge but offer no evidence to support the claim |
| 3 | Students begin to offer evidence to support their claims |
| 4 | Students offer further evidence to support their claim |
| ± 5 | Students respond to ideas from others in the group |
| 6 | Students are able to sustain an argument in a variety of ways |
| ± 7 | Students evaluate the evidence and make judgments |

Key levels: +1 = students are willing/able to enter into discussion; +2 = relevant claim to knowledge, - 2 = irrelevant claim to knowledge; -5 = no response from students to ideas from others; -7 = students unable to evaluate the evidence or to make judgements.

3.21.3 Modification of analytical framework- CAT

Essentially CAT identifies five cognitive states: dominant, suppressing, assimilating, equipollent and emergent. During each of these stages, there is a unique level of analysis, internal organization and understanding of cognitive shift that happens in the mind of the learner. I have decided to modify the first stage of CAT, the ‘Dominant’ in order to extract, interpret without generalization the sources of pre-service teachers’ knowledge.

In an effort to fulfil the purpose of the study, I am interested to establish when ideas are dominant; and in what source of knowledge they are dominant. I have defined two possible sources of dominance according to the responses (data) collected from the pre-service teachers. I have noted that responses in the data are either scientific or commonsensical knowledge dominant. The original CAT did not make provision for this. For this reason, I have made an alteration in the CAT ‘dominant’ stage. I define responses based on dominant commonsensical knowledge as {CAT stage – 1} and scientific based knowledge as {CAT stage +1}. The modified version is shown in Table 3.3.

Table 3.3 The five Stages of CAT modified after Ogunniyi (2007a & b)

| CAT Stages | Adaptive co-existence that occurs within a student confronted with two distinct forms of thought/constructs: <i>Logical and Non-logical features</i> |
|---------------------------|---|
| Dominant (± 1) | One thought system or explanation is seen to be more convincing or more appropriate than another at that moment and for that context. Or a powerful idea explains facts and events more effectively and convincingly than another idea, or else resonates with the acceptable social norm that affords an individual a sense of identity. |
| Suppressed (2) | One thought system is seen to be less convincing than another. The less convincing or subordinate thought system becomes suppressed. An idea becomes suppressed (it is not allowed to come out) in the face of more valid, appropriate, adequate and convincing evidence. |
| Assimilated (3) | The dominant thought system is taken by people who initially held the suppressed thought system. The initially held system is supplanted or subsumed by the dominant worldview. This means that a less powerful, less convincing idea is assimilated (taken in, swallowed) by a more powerful, a more persuasive idea. |
| Emergent (4) | No previous idea, opinion or position on an issue really exists in the learner. An idea emerges as the individual is exposed to new teaching. For example, many science concepts learnt at school are really new to the indigenous learners and are added to the indigenous worldview of the learner (Ogunniyi, 2011). |

- Equipollent** The two competing thought systems are seen as equally powerful, adaptable, active, effective or significant in making sense of the observed phenomena. The two rival thought systems coexist and exert equal cognitive force on a person's beliefs. For example, a person could find both creation and evolution as attractive explanations for the origin of the universe and humankind (Ogunniyi, 2011).
- (5)

Key: Stage -1 = commonsensical knowledge dominant; Stage +1 = scientific knowledge dominant

3.21.4 Analytical definition of the use of the nature of arguments in the study

The term argumentation will be used to refer to the whole activity: making claims, challenging them, backing them up by producing reasons, criticizing those reasons, rebutting those criticisms, and so on. The reference to pre-service teacher(s)' reasoning will be used, more narrowly, for the central activity of presenting the reasons in support of a claim, to show how those reasons succeed in giving strength to the claim.

An argument, in the sense of a train of reasoning is the sequence of interlinked claims and reasons that, between them, establish the content and force of the position for which a particular pre-service teacher is arguing. In this respect, when a pre-service teacher participates in an argument, s/he shows his/her rationality, or lack of it, by the manner in which s/he handles and responds to the reasons offered for or against claims. If s/he is "open to argument," s/he will either acknowledge the force of those reasons or seek to reply to them, and either way s/he will deal with them in a "rational" manner. If s/he is "deaf to argument," by contrast, s/he may either ignore contrary reasons or reply to them with dogmatic assertions, but either way s/he fails to deal with issues "rationally" (Toulmin, Rieke, & Janik, 1984).

3.22 Statistical Data Analysis

One of the usual methods used for judging the importance of a difference between the means of two set of scores, say, pre-post tests is what is called inferential statistics. It is common to find, even before examining polygons or differences in means, that a researcher has applied an inference technique (a t-test, an analysis of variance, and so on) and then used the results as the only criterion for evaluating the importance of the results. This practice has come under increasing attack.

For example, at one extreme are the views of Carver (1993) and Schmidt (1996), who argue that the use of statistical inference tests in educational research should be banned. A few years later, according to Mittag and Thompson (2000), a survey of AERA members (American Educational Research Association) indicated that 19 percent agreed to the views held by Carver and Schmidt.

At the other extreme are those who agree with Robinson and Levin (1997) that “authors should first indicate whether the observed effect is statistically an important one, and only if it is should they indicate how large or important it is (is it a difference that makes a difference). Cahan (2000) argues, to the contrary that the way to avoid misleading conclusions regarding effects is not by using significance tests, but rather by using confidence intervals accompanied by increased sample size.

In 1999 the American Psychological Association Task Force on Statistical Inference recommended that inference tests not be banned, but that researchers should “always provide some effect size (SE) estimate when reporting a p value,” and further, that “reporting and interpreting effect sizes in the context of previously reported research is essential to good research.” It is thus necessary to keep alert to the recommendations of the aforementioned authors. These have been fundamental to the subsequent analysis in this study.

3.23 Ethical considerations

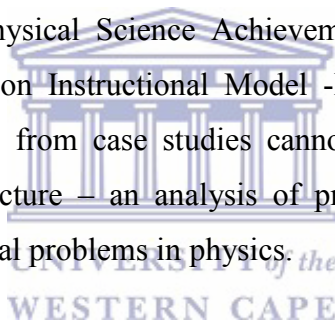
Permission to conduct the study was obtained in writing from all the relevant parties (see Appendices: A1, A2, and B). Also the requirements for conducting the study laid down by the University of the Western Cape were adhered to and the Ethical Code of Conduct Form was completed and submitted to the Dean of Research through the Education Research Committee.

The purpose of the study was explained in writing to the relevant parties. Research participants were informed verbally in addition to the consent letter given to them. Participation in the study adhered strictly to the condition that data collection be in line with tuition for all the first year physics students. As such, all students were encouraged to participate.

Confidentiality was ensured in that the research participants' identities and interests were protected. To demonstrate this, the techniques and methods for this study did not require their personal details, such as names or student numbers. Instead, alphabetical letters were used throughout the study and findings were promised to those interested. Participation was voluntary and participants were told that they could withdraw if they were not pleased with the conduct of the study. The participants were properly oriented and also encouraged to be honest in all the paper work such as answering the questionnaires and interviews.

3.24 Summary

Data was collected over a period of one semester (6 months) of interaction and observation with first year pre-service science teachers, thus providing me with substantial data on argumentation in classroom interaction within their specific contexts. Data was extracted on the pre-service science teachers' performance (Physical Science Achievement Test-PSAT) in terms of their approach (Dialogical Argumentation Instructional Model -DAIM) and on the basis for their actions (interviews). The findings from case studies cannot be generalized, but can provide insight into aspects of the big picture – an analysis of pre-service science teachers' use of argumentation to solve mathematical problems in physics.



CHAPTER FOUR

PRESENTATION OF FINDINGS AND DISCUSSION

4.0 Introduction

In this chapter entails data analysis and presentation of the findings in terms of quantitative and qualitative descriptions followed by discussion. The analytical tools, CAT and DAM in conjunction with each other are used to assess and discuss the findings in relation to the extant literature. Also, a concerted effort will be made to show how the different categories of CAT and DAM fit together to elucidate how argumentation instruction can be used by pre-service science teachers in solving mathematical problems in physics. In addition, the analysis seeks to ascertain whether or not their ability and sense of self-efficacy in solving mathematical problems in physics has improved over the course of this research.

The results are presented under headings derived from the two research questions posed in Chapter 1. These are: (1) Identify the nature of argumentation strategies that pre-service science teachers use to solve mathematical problems in physics; and (2) Determine the effectiveness of a dialogical argumentation instructional model (DAIM) on their ability and sense of self-efficacy to solve mathematical problems in physics.

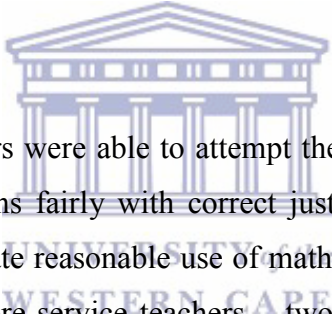
The findings are presented in two sections. Findings of the quantitative instrument are presented first, followed by the findings from qualitative data.

4.1 RESEARCH QUESTION 1: What types of argumentation strategies did the pre-service science teachers use in solving selected mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM)?

In general, four phases of observations (O1–O4) were undertaken, from which data was collected. Twelve content-based mechanics problems, items 1.6 – 7.6.4, of Appendix C, were used specifically to examine pre-service teachers' ability to use the dialogical instructional model to solve mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM). Responses were categorized and analyzed using SPSS (version 23).

For the context of mathematics use in physics problem solving, each of the PSAT items was scored out of a maximum of 8 points. The first part (correct /incorrect solution) was out of 3 points and the grounds provided were out of 5 points.

By using SPSS (version 23), items related to math-in-physics problem-solving were guided by the following descriptions: Incorrect, with no justification D = 0; Incorrect, with justification C = 1; Correct, with no justification B = 2; and Correct, with justification A = 3. In terms of “Grounds” provided by the pre-service teachers: No grounds E = 1; Single grounds D = 2; Multiple grounds C = 3; Single/Multiple grounds with counter-claim B = 4; and Single/Multiple grounds with counter-claim and rebuttal A = 5. From this SPSS' permutations, a descriptive key was generated (AA=8pts; AB=7, AC=6, AD=5, AE=4, BB=6, BC=5, BD=4, BE =3, CC=4, CD=3, CE=2, DD=2, and DE=1). These descriptions guided my analysis, hence the results and discussion that follow.



Six out of forty pre-service teachers were able to attempt the 12 PSAT activities at observation (O1), and to support their decisions fairly with correct justification in the BB category. This means they were able to demonstrate reasonable use of mathematics in physics problem solving in the DAIM setting. Four other pre-service teachers – two each – completed the 12 items at categories AA and AB levels, meaning that these pre-service teachers were able to mobilize mathematical concepts needed to solve the given problems. Another indicator of these categories (AA and AB) shows that the four pre-service teachers were able to provide justifiable arguments pertaining to a given problem and its possible solution.

Further, ten more pre-service teachers – five each – did so at categories BC and BD levels. This means they could only solve problems with fewer mathematical difficulties, and have adequately used the numerical answers they calculated at certain stages of the given problems to solve follow-up problems correctly. The ability they exhibited might have led them to provide some correct and incorrect justification for different problems of the PSAT.

Figure 4.1 below shows the overall results of how the pre-service teachers performed at observations O1 and O2. In this regard, pre-service teachers whose points fall within the five categories BE, CD, CE, DD and DE (according to the descriptions discussed earlier) are considered very poor problem-solvers. This is because the points of such categories are below half the maximum points (8 points) expected of a pre-service teacher when s/he has solved PSAT activities correctly, with justification; and when s/he has provided single/multiple grounds, with counter-claim/s and rebuttal/s to support the solution obtained.

In addition to the foregoing, it is also evidenced that pre-service teachers had a tendency to grapple with conceptual resources in mechanics and with the manipulation of equations. As a result they could not progress in solving given problems effectively. This became evident during group presentation. But, Sabella and Redish (2007) believe that because physics problems are typically quantitative, focusing on finding appropriate formulae and manipulating the equations to solve for a numerical value, is indeed one aspect of being proficient in physics problem solving. This advice was not feasible within my study as pre-service teachers who manipulated equations by plugging known quantities to find the unknown variables wasted so much time and could not arrive at any reasonable solutions.

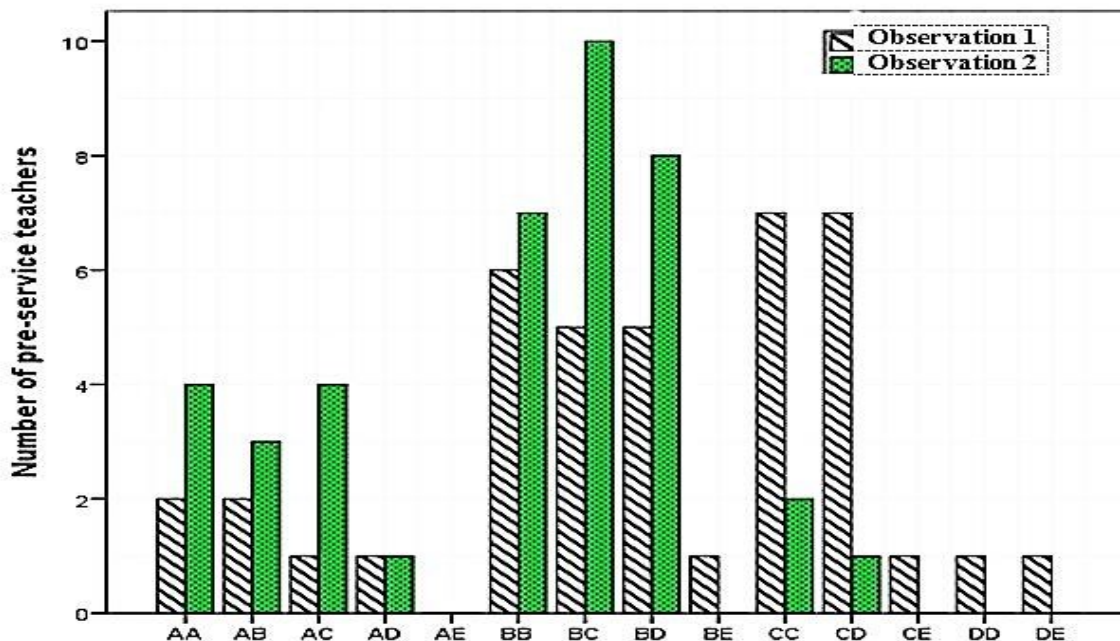


Figure 4.1 Pre-service teachers' observations (O1 and O2) on 12 PSAT items

As noted, observations made between O1 and O2 show that some of the pre-service teachers who were not able to solve the tested items at O1 level were able to do so at O2 level. Those who attained categories BC, CC and BE at observation-O1 for items 1.6- 1.7 (concerning everyday science), later on at O2 level, attained categories AB, BB, and AD. This showed a shift from being commonsensical knowledge dominant [CAT stage – 1] to being scientific knowledge dominant [CAT stage +1].

Moreover, attainments of such levels of categories, in particular AB and BB, are associated with learning across other stages of CAT. For example, it is possible that the pre-service teachers may have revised their thoughts and cognitions of initial responses at O1 level. Such processes, and later refutations (at observation O2) led to a shift from scientific ideas initially suppressed [CAT stage 2] to scientific ideas assimilated [CAT stage 3], due to their willingness to enter into dialogue with their peers [DAM levels: +1, 4, 5, 6 and +7]. These processes were also evidenced in the quality of the argument they produced leading to the attainment of the aforementioned categories. This cannot be said for all the pre-service teachers. Some of them, as noted, often get stuck using a limited group of skills or limited reasoning, and fail to notice that a different set of tools (which they do possess and know how to use effectively) could quickly and easily solve their problem.

In addition early research on physics problem solving suggests a difference between novices and experts. Novices tend to start by selecting and manipulating equations that include relevant known and unknown quantities. By contrast, experts tend to start with a conceptual analysis of the physical scenario, which then leads into the mathematics (for example, Chin & Chia, 2004; Dreyfus et al., 1990; Heller et al., 1992; Kuo et al., 2013; Larkin & Reif, 1979). Partly for this reason, eleven pre-service teachers were trapped in the five poor categories indicated earlier: BE, CD, CE, DD and DE.

Moreover, at observation (O2), thirteen pre-service teachers, five for category (AA level), three for category (AB) and six for category (AC) were considered as better problem-solvers of the 12 PSAT activities. This means that they did not only demonstrate the ability to mobilise mathematical concepts to solve physics problems of mechanics, but they were also able to

provide justifiable arguments pertaining to a given problem and its possible solution. Another possible verifier of their abilities in the aforementioned categories is that the pre-service teachers were able to interpret numerical answers to see whether the answer(s) they had obtained made sense or not.

In addition seventeen pre-service teachers attempted the 12 items with justification at categories BB and BC levels at observation O2. It is reasonable to regard the pre-service teachers at BB as good problem-solvers and those at BC as fair problem solvers in that they were all able to mobilise mathematical concepts to solve physics problems of mechanics. They also provided fair justification for the solutions they obtained. Eight more pre-service teachers solved the items with justification at category BD level. These pre-service teachers are regarded as average problem-solvers.

At Observations O1 and O2 levels, only two pre-service teachers (one at each observation), attempted the 12 PSAT activities at AD category level. This means they were to some extent able to mobilize mathematical concepts to solve some of the given problems and could provide justification for some of the solutions they obtained. From this category, it is also possible that these pre-service teachers did not fully interpret the numerical answers they obtained to see whether they made sense or not.

These results support early findings on the use of mathematics in physics problems as many physics students struggle to develop mathematical fluency (Bing & Redish, 2009). They are unable to use equations to obtain a mathematical solution in a mathematical processing step (Heller et al., 1992).

The results from the current study extend previous research findings in the domain of problem-solving in physics, such as difficulties students faced in creating representations of a given problem before solving it (Larkin & Reif, 1979). Students also commonly face challenges recalling knowledge relevant to solving a given problem (Shin et al., 2003). Students have however demonstrated the ability to keep track of a given problem prior to solving it (Sherin, 2006),

but have had problems monitoring whether the results obtained are consistent with other known information (Reif, 2008; Mualem & Eylon, 2010).

As is evident, pre-service teachers' ability to solve the 12 items at observations O1 and O2 levels, indicates a variation. A common attribute to such variation is lent to the DAIM which provided the required social interaction for the pre-service teachers to engage in dialogue so as to see various and diverse perspectives on any issue. Thus the goal of DAIM is to enable pre-service teachers to attain cognitive harmonization. This is to be attained by their shifting from an individual view of themselves to an identity as a member of a community (small group). Viewed thus, even individual pre-service teachers who solved the items efficaciously (enactive mastering) after they had worked in their small groups, may have done so through reflection in which they create shared knowledge and tacit understandings.

In line with self-efficacy constructs, various factors could have been responsible for the variation. These include social persuasion, vicarious learning, and physiological arousal (motivation) which pre-service teachers would have encountered as they worked in small groups. Thus the DAIM's emphasis on self-efficacy and assessment of tasks forms the rationale for its application to my study.

4.2 Pre-service teachers' performance on PSAT at observations (O3 and O4)

Observation O3 was taken soon after pre-service teachers returned to lectures from their two-week holiday. Six pre-service teachers, three each attempted the PSAT activities at categories AB and AC. None were noted at category AA level. A slight decline in the pre-service teachers' mode of learning was noted. Even so, there was a notable tendency amongst many pre-service teachers to return to their new-found approach to learning. Their asking one another's approval before completing a given task could have reflected one of the values that the DAIM advocates as experience to be gained in a community of practice.

At observation O4, about fourteen pre-service teachers were able to attempt the 12 PSAT activities; twelve did so at category level AB and two solved the items correctly. A significant

increase was noted in the number of pre-service teachers who attempted the items at observations O3 and O4 at AC category level; a three-to-five increase was recorded.

Figure 4.2 shows that seven pre-service teachers improved not only the quality of their argument about the 12 PSAT activities at observation O4 (category BB), but that they were able to defend their choice of solution to math-in-physics problems with correct reference to scientific content. This showed significant progression with respect to observation O3. Only one pre-service teacher was able to defend his decision in a correct way from scientific a viewpoint (see Figure 4.2).

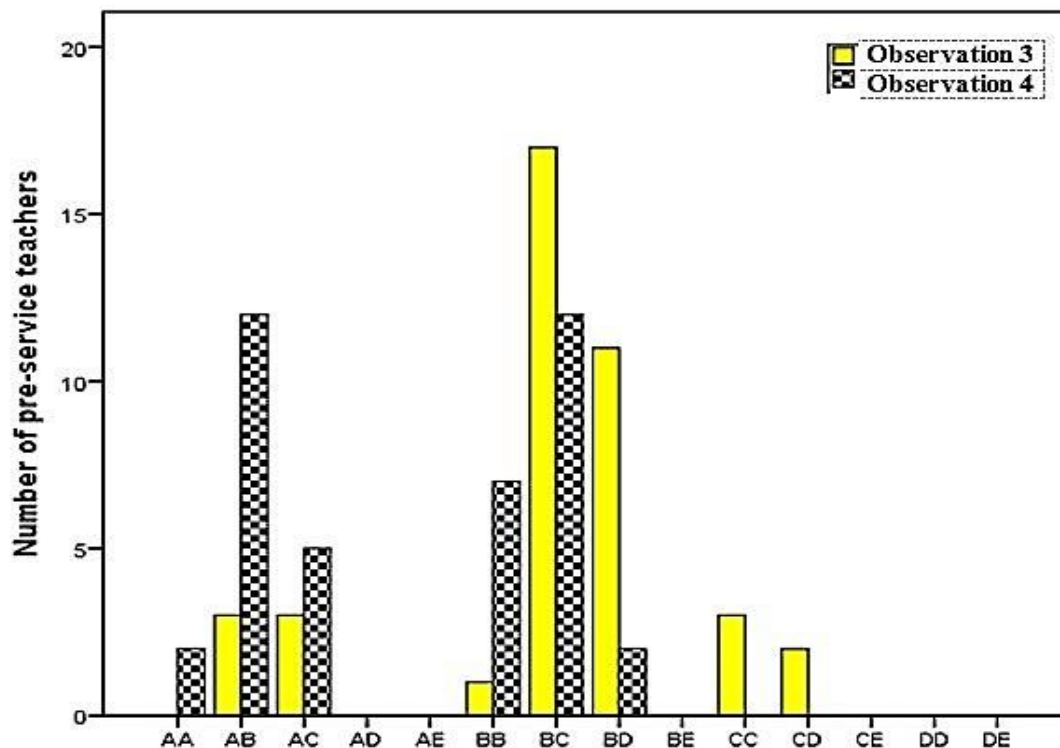


Figure 4.2 Pre-service teachers’ performance on 12 PSAT items at observations O3 and O4

At both observations O3 and O4 none attempted the items at categories AD and AE levels. During observation O3 there was a decrease in the number of pre-service teachers. About thirty-percent attempted the PSAT activities at category BC level compared to forty-three percent who did so at observation O4. Viewed from Figure 4.2, this decrease thus translates into the fact that more pre-service teachers gained entrance between the categories AA, AB, and AC, predominantly in the AB category, indicating that those who did so had moved from being

average problem solvers to good problem solvers. If the latter assumption is positioned differently, on the one hand, it translates into a major cognitive shift over the first observation (O1) and the final observation (O4). On the other hand, it translates into more evidence of improvement between the times the intervention programme (DAIM) was introduced and the aftermath as can be seen in observation O2.

Another verifier of the latter assumption can be seen in Figure 4.2. This is that no pre-service teachers were recorded between the categories of average and very poor problem solvers, that is, CC, BE, CD, CE, DD and DE. This means that over time pre-service teachers had improved their ability to use the nature of arguments to solve math-in-physics mechanics problems (observation O4).

4.3 Possible impact of DAIM on Pre-service teachers' performance on PSAT

The analysis presented in Table 4.1 was computed using SPSS. Results in Table 4.1 show a host of significant effects. They show that the treatment had a very large effect ($\beta_{64} = 0.5162$), yielding an odds of $\exp(0.5162) = 1.67566$, which converts to a proportion of $P = \text{odds} / (1 + \text{odds}) = .626$. That is, the odds at that point where pre-service teachers exhibited their ability to solve mathematical problems in physics. For the change from the first observation to the second – O₁ to O₂ – the change in odds suggested that there was little consistent trend in general and that treatment had a minimal effect compared to the O₂ to O₃ pair and O₃ to O₄. The interaction between treatment and session was also not significant, suggesting that the treatment was about as effective in the O₃ to O₄ pair as in the first O₂ to O₃ pair.

Table 4.1 Pre-service teachers' performance on PSAT at observations (O1 – O4)

| <i>Effect</i> | <i>Coefficient</i> | <i>Standard error</i> | <i>t-observe</i> | <i>df</i> | <i>t-critical</i> | <i>p-value</i> | <i>Odds ratio</i> |
|------------------------|--------------------|-----------------------|------------------|-----------|-------------------|----------------|-------------------|
| β_{00} Intercept | 0.18080 | 0.40709 | 0.534203 | 38 | | 0.596396 | 1.19817 |
| β_{64} treatment | 0.51621 | 1.155641 | -6.39075 | 38 | | <0.010482 | 1.67566 |
| β_{8} O1 to O2 | 0.08748 | 2.211044 | -5.49688 | 38 | 2.024394 | 2.79E-06 | 1.09142 |
| β_{16} O2 to O3 | 0.26330 | 2.023992 | 3.534523 | 38 | | <0.001093 | 1.30121 |
| β_{24} O3 to O4 | 0.40527 | 1.648127 | -9.16347 | 38 | | 3.65E-11 | 1.49970 |
| β_{64} Session | 0.141767 | 1.508202 | 2.696597 | 38 | | <0.010482 | 1.15230 |

Moreover, the overall results of O_1 to O_4 tend to suggest the treatment had an effect on improving pre-service teachers' ability to use the nature of dialogical argumentation instructional model (DAIM) to mobilise mathematical concepts needed to solve physics problems of mechanics. However, the effects of treatment vary in a complex way depending on O_1 to O_2 pair, O_2 to O_3 pair, O_3 to O_4 pair and the session, suggesting that pre-service teachers varied significantly, not just in their response to treatment but in many other main effects and interactions. This can be said to be an accurate rendition, given what we shall see later in Figures 4.11 and 4.12 respectively. From Figures 4.11 and 4.12 as well as results in Table 4.1, a clear treatment effect does seem apparent, but the size and consistency of that effect also seems to depend on the pre-service teachers, whether one looks at the first or second O_1 to O_2 pair, and at the session within those pairs.

4.4 Individual versus Group math-in-physics problem-solving (including observation made from the classroom video-camera)

In this section, I focus on the individual-group transfer paradigm seeking to know at which phase pre-service teachers were able to transfer their argumentation skills to a problem requiring a different nature of argumentation skill.

Pre-service teacher PT18 was able to solve item 6.3.4 individually using a different kind of argumentative skill approach. To do this, PT18 blended qualitative reasoning with semiotics (making sense of signs and symbols and their use or interpretation in math-in-physics problems). This then gave her the leverage to set up an appropriate math-in-physics equation, which she later used for mathematical computation of the problem.

Beyond this heuristic demonstration by PT18 (that is, self-discovery strategies that enabled her to use math-in-physics concepts effectively), an idea emerges as she is exposed to new teaching, that is, argumentation [CAT stage 4]. As with her fellow participants when in a small group, she used the underlying math-in-physics concepts differently. The same applies to the kind of argumentation to justify the solution she obtained [DAM levels 6 & 7]. It is also evident that PT18 has successfully used the nature of arguments to solve math-in-physics problems (as required in item 6.3.4) and that she had leverage on the group with whom she worked.

A study conducted by Johanness et al. (2009) comments that successful argumentation requires a problem solver to develop a solution, support the solution with evidence, and consider alternatives. These characteristics noted in the works of Johannes et al. (2009) do not fall short of characteristics demonstrated by PT18.

In this study, what I observed during pre-service teachers' math-in-physics problem-solving activities and discussions is that although mathematics is an essential component of university level physics, math-in-physics is considerably more complex than the straightforward application of rules and calculation taught in mathematics classes. Such observations then warrant clarification of the subtle differences between mathematics and physics.

Mathematics as a subject is based largely on logic while physics translates or applies logic to physical phenomena or a physical reality, as exemplified by math-in-physics problems. In other words, mathematics deals with any possible world real or unreal, but physics deals with both an idealistic and the real physical world where we live. Thus my observations have led me to conjecture that few pre-service teachers who gained problem recognition prior to solving math-in-physics, demonstrate the complex skills of mixing different classes of reasoning skills – the ability to blend physical, mathematical, and computational reasons for constructing and believing the solution(s) they produce. This observation suggests that such pre-service teachers are somewhat comfortable dealing with math-in-physics problems.

Bing and Redish (2009) ask what it means “to become comfortable with math-in-physics”, how would we recognize it happening in a student, and how, as instructors, can we facilitate this process? These authors argue that using math-in-physics critically involves the blending of ancillary information with the mathematics in a way that changes both the way equations are interpreted and the way metacognitive support for recovery from errors is provided. As soon as the pre-service teachers were introduced to DAIM, most of them struggled as they tried to develop the mathematical fluency needed to solve Physics mechanics, for example, motions in 2D. Part of their struggle was probably due to the conceptual complexity of the mathematics commonly encountered in physics 1 mechanics classes.

Several studies in the literature reviewed have shown that most students need some mathematics experience prior to studying physics, since mathematics is the language we use to understand and communicate physics as well as other sciences (Junkins, 2007; Martinez-Torregrosa et al., 2006; Redish, 2005).

In the South African context, a few studies acknowledge the prevalence of student anomalies based on their intellectual strategies to solve both mathematics and physics problems. Recently, Ndlovu and Brijlall (2016) investigated the pre-service teachers' mental construction of the determinant concept. Of the 31 pre-service teachers in their study, they found that many of them failed to generalize the formula for evaluation needed for solving the given task, with the exception of a few who managed to demonstrate the required operation.

In another recent study done in South Africa, Govender and Dega (2016) studied third year pre-service teachers' conceptions of mechanics. As with the present study which has implications for the teaching and learning of basic mechanics, they found that pre-service teachers in their study displayed a lack of higher level conceptual understanding of vector-kinematics.

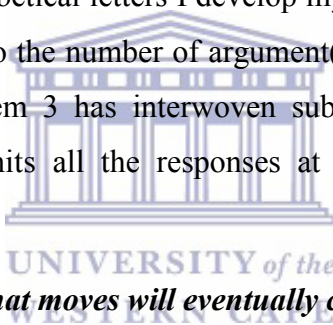
In earlier research Nguyen and Meltzer (2003) investigated pre-and-posts of students' knowledge of vectors in introductory mechanics courses. Their findings suggest that over one quarter of the students completing a calculus-based mechanics course and one-half of the students completing the algebra-based course were unable to resolve vectors in two dimensions.

Elsewhere, Bing and Redish (2009) expressed that mathematics fulfills many different epistemic roles for a physicist. It reflects physical relations, provides a calculation framework, forms a web of interconnected ideas and provides a packaging system for encoding rules and previous results. What has been gained from the ongoing findings and the extant literature is that to teach physics effectively, it is necessary for pre-service teachers to be competent in a complex web of knowledge domains: knowledge of and about math-in-physics and about pedagogy of physics.

4.5 Pre-service teachers' dialogical argumentation by level

Item 3 consists of nine sub-items. In this section I use both CAT and DAM side by side to identify the principal components of an argument contributed by individual pre-service teachers in their small groups. For ease of reference, the levels/stages used for backing a given claim are enclosed as follows: DAM levels of arguments are in the [first bracket], while the stages of CAT reflected in such a claim or stance have been placed in the {second brackets}. The set of examples that follows is provided to illustrate how the analysis has been applied to the data.

From this section to the end of the pre-service teachers' arguments, I use a numbering system ranging from 1-217 beside their responses, with the exception of sessions of group responses. But where necessary I have used alphabetical letters to classify different groups. By using the numbering system as well as alphabetical letters I develop my discussion. Each time I cite a pre-service teacher's response I refer to the number of argument(s) to help the reader make sense of it at that point in time. Since Item 3 has interwoven sub-items, I have decided to provide interpretative commentary that knits all the responses at the completion of the pre-service teachers' responses.



4.5.1 Item 3 reads: Everything that moves will eventually come to a stop. Being at rest is the “natural” state of motion of all objects.

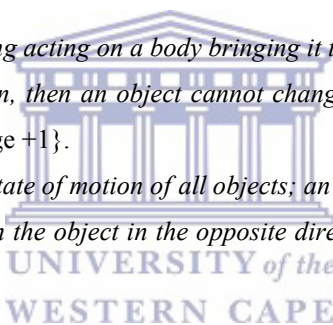
Of all physics misconceptions, this is probably the most common. Even the great philosopher Aristotle, included it in his most important contribution to the field, his famous Laws of Motion. But now we know it is wrong because Newton's First Law of Motion tells us that “*everything at rest will stay at rest, and everything in motion will stay in motion, unless acted upon by an external force.*” Here are some of the excerpts provided by the pre-service teachers:

1. PT29. *I agree.* [..with Aristotle notion]
2. PT8. *Disagree*
3. PT15. *Disagree*
4. PT10. *Disagree*
5. PT22. *Disagree*

4.5.2 Item 3.2: *If you agree (with item 3), state why If you disagree, state why*

Following pre-service teachers' stances on item 3.1 and item 3.2 they were then asked to state whether they agreed or disagreed with that claim. Out of the forty pre-service teachers who responded to the item, thirty-three of them disagreed with the statement and the rest (seven) agreed. The excerpts below are representations of their views:

6. PT29...*A moving object moves, only because a force(s) are being exerted on it. If no force is put on an object at rest, the object will remain at rest. (Newton's laws of motion).* [DAM levels +1 & -2] {CAT stage -1}.
7. PT8...*Because everything in motion will stay in motion unless acted upon by an external force.* [Newtonian][DAM levels +1, +2 & 4] {CAT stage +1}.
8. PT15...*According to Newton's First Law of motion, an object will remain in its state of rest or motion unless acted upon by an external force.* [DAM levels +1, +2 & 4] {CAT stage +1}.
9. PT10...*Because if there is nothing acting on a body bringing it to rest, in other words no force to cause deceleration, then an object cannot change from a uniform motion.* [DAM levels +1 & +2] {CAT stage +1}.
10. PT22...*Rest is not the natural state of motion of all objects; an object will only stop if there is an equal force acting on the object in the opposite direction of motion.* [DAM levels +1 & +2]



4.5.3 Item 3.3: *One of your classmates may disagree with you. What might their alternative be?*

11. PT29... *No response.* [DAM level -1]
12. **Prodding:** Why are you quiet PT29? You said nothing...
13. PT29... *I think I was wrong when I said I agree to the claim.* [DAM level -2]
14. **Prodding:** Why do you think so?
15. PT29... *The statement is not true because Newton's law says if an object is moving, it will keep moving unless an external force acts on it.* [DAM levels +1, +2, 4 & +7] {CAT stage +1}
16. **Prodding:** Does it mean you've changed your mind?
17. PT29...*Yes Sir, I disagree to the statement.* {CAT stage 2}
18. **Prodding:** What made you changed your mind?
19. PT29...*too much questions...hmm...from what others are saying, made sense, so, yeah.* {CAT stages 3} [DAM level +5]

20. **Prodding:** That's okay, I leave you for now.
21. *PT8... They might think objects stop moving because there is no force applied to make it move.*[DAM level -5]
22. *PT15... No response.* [DAM level -1]
23. *PT10... that the energy of a body gets expended by the movement.* {CAT stage -1}
[DAM level -2]
24. *PT22...object will be at rest if no force is exerted.* {CAT stages +1}[DAM level +5]

4.5.4 Item 3.4: Explain why you would accept or discard your classmates' alternative view(s) about the claim

This item includes discussions containing claims or counterclaims, with grounds and only a single rebuttal that challenges the thesis of the claim according to Downing (2007) [Levels 4-7] of arguments. To buttress these levels of arguments, five stages of CAT {stage 1 – 5} are used to distill ideas that are likely to occur: emergent, dominant, assimilated, suppressed or equipollent.

25. *PT29... Newton's laws of motion. These laws have been proven. Also based on investigation.*
[DAM levels +1, -2]
26. **Prodding:** Which of the Newton's laws of motion are you referring to?
27. *PT29...I'm not so sure which of them, I guess the Second one, sorry it's First law.*
[DAM levels +1, +2, 3 & +7]{CAT stages +1, 2 & 3}
28. *PT8...if an object is stopping, then there must be net force acting on it.* [DAM levels +1, +2, +5]
29. *PT15... No response* [DAM level -1]
30. *PT10... I would discard their alternative notion based on the law of conservation of momentum*
[DAM levels +1, -2, +5]
31. **Prodding:** Why do you think this? Can you elaborate more?
32. *PT10: Nothing can be at rest as it is always moving relative to something else.*
{CAT stages +1}[DAM levels +1, -2, 3, +5]
33. *PT22...because objects are always in motion unless an external force opposes their motion.*
{CAT stages +1}[DAM levels +1, +2, 3, +5]

4.6 Interpretative Commentary

The first part of item 3 seems reasonable enough, but the second part is a little bit murky. The reason this confusion persists boils down to the fact that we are unable to identify the force that stops all motion, which is friction. Friction is a force that acts between two objects that are in contact and are moving relative to each other. For example, when we roll a ball, it stops because

of the frictional force acting between it and the floor. The discussion here tends to be relatively unsophisticated in terms of scientific discourse.

At observation O1 pre-service teachers tend to accept the claims of their peers and move on. In most discussions few pre-service teachers included grounds for their statements. For instance, “*everything that moves will eventually come to a stop. Being at rest is the “natural” state of motion of all objects*”. Several misconceptions were detected in the physics principles provided by pre-service teachers. For example, PT29, see lines 6 and 25 of the arguments, for PT10 see lines 30-32. In backing arguments a pre-service teacher (PT29) cited Newton’s laws of motions with no specification. We cannot ask whether her stance is correct or not. We can only say she has some idea about the matter at stake.

On the basis of a logical process, her justification is vague as she does not define or specify which of Newton’s laws of motions she was using to back her argument. I termed the pre-service teacher’s notion as a common anomaly, as it is an idea that deviates from the orthodox version. Support evidence may be seen in the pre-service teacher’s backing in that, she says, “these laws have been proven and investigation has been conducted.” When refutations ensued, she saw the need to have a re-think. As she tries to deal with the *anomaly* she holds, she cites “Newton’s first law” [CAT stage 3]. In line with PT29’s rethink, Schwarz (2009) states that the process of acquiring argumentation skills requires that participants communicate their viewpoints, consider assumptions in their personal theories and rethink their original ideas based on the new information.

If, in pursuance of her resolution of anomaly, we supplement her new specified notion “Newton’s First Law” as a single proposition to her arguments (Line 25 of argument), then she is justifiable in her latter stances [DAM levels 3 & 4]. Pre-service teacher (PT10) had a need to back his argument when he was asked why he would accept or discard the alternative notion produced by his peer on the same item he disagreed with. He backed his argument by citing “the law of conservation of momentum” (see line 30 of arguments). When he was asked why he thought this he explained, “Line 32” of arguments. A closer look at PT10’s earlier justification

(see line 6 of arguments) seems to conform to Newton's First Law. Even so, it is either incomplete or void to the actual law.

In order to attain the greatest possible clarity of all PT10's responses to the items, let us return to his lines of argument (lines 9, 23, 30 and 32). Let us imagine him saying he "disagreed" (line 4 of arguments) with the statement because "if there is nothing acting on a body bringing it to rest. In other words, if there is no force to cause deceleration, then an object cannot change from a uniform motion" (line 9 of arguments). In this connection he made, his justification for disagreeing with the statement attained some scientific meaning {CAT stages +1 & 3}, but this rosy cognitive exercise was short-lived as subsequent items required him to strengthen his arguments.

In view of this dilemma faced by PT10, it appears that he had nothing else left to say than to abandon his initial thoughts {CAT stage 2}. This was evident given the way he ended his arguments (see line 32 of arguments). We have seen his assumption is incompatible with his initial response (see line 9 of arguments). If we discard his assumption (line 30 of arguments), then the conflict between (lines 9 and 30), disappears. Hence it cannot be contended that he had given a correct scientific response about the item at stake {CAT stage -1} and [DAM level -2]. Under this condition we understand he had led himself and us to conflict by the advent of his latter response "nothing can be at rest as it is always moving relative to something else" (see line 32 of arguments). When a conflict arises in the mind of a student as a result of being exposed to school science, the contiguity argumentation theory (CAT) suggests that a sort of "internal argument" or "conversation" ensues within him between competing schemata in the working memory where consciousness in an individual is assumed to be most active (Ogunniyi, 1997).

From the foregoing, it seems that the pre-service teachers often simply state agree or disagree and repeat the portion of the comment with which they agree or disagree. Only a few statements include grounds. In such instances, they explain why they agreed or disagreed in their initial claims. Many of the pre-service teachers (such as PT10, PT8, and PT22) were able to support their claims with justifications and some even provided alternative perspectives with justifications (see lines 6-10 of arguments). Although some pre-service teachers tried to refute

arguments, their rebuttals were weak or inadequate (see lines 11-24 of arguments). By contrast, research indicates that as rebuttals become more clearly identifiable the quality of arguments improves (Clark, Sampson, Weinberger, & Erkens, 2007). This is because rebuttals indicate the quality of arguments in that they challenge participants to evaluate the validity and strength of arguments (Erduran, 2007).

Many of the pre-service teachers (PT15, PT29 & PT10, see lines 25-31) could not recognize the grounds of the opposing opinions, much less undermine them. It may be even more difficult for them to recognize rebuttals on the grounds that they use to defend their arguments. The absence of rebuttals to arguments might have been due to a lack of emphasis by my colleague who facilitated scaffolding of argumentation skills to the pre-service teachers on different occasions.

For example, observations O2 and O4 were facilitated by my colleague on writing arguments. Traces in pre-service teachers' work revealed that they were not clearly instructed to defend or refute their claims. Thus, it is unclear whether or not the pre-service teachers attempted to rebut the arguments of their peers because they could not undermine them. In this regard, Ogunniyi (2007a) asserts that certain conditions are necessary if argumentation is to be done effectively. These conditions include what he describes as: the ability to follow an argument (clearly a good grasp of the language used and mental alertness are critical for this to happen); a willingness to learn something new and so on.

Moreover, the use of rebuttals is limited by the pre-service teachers in order to refute the elements of an argument that are proposed by their peers. The limited use of grounds and rebuttals by the pre-service teachers can be attributed to the fact that argumentation does not appear to be a common feature of the science classroom. Studies have shown that although the students are able to generate claims, they usually do not provide grounds for these claims (Jimenez-Aleixandre et al., 2000; Kelly, Druker, & Chen, 1998; Skoumios & Hatzinikita, 2008). When grounds are included as part of an argument, many students tend to rely too heavily on unsubstantiated explanations to justify their claims (Kuhn, 1991) or they simply use plausible explanations as a way of replacing missing evidence (Brem & Rips, 2000).

As a further factor, Simon et al. (2003) found that, during face-to-face student discussions, 32% of the oppositional episodes include clearly identifiable rebuttals while the majority of the oppositional episodes involve arguments that consist of claims with grounds but without rebuttals. What then can be blamed for the poor use of rebuttals by pre-service teachers? Could it be that the use of argumentation instructional constructs such as claim, data, warrant, rebuttal, and so forth may have posed language issues to the pre-service teachers? If the latter was a contributing factor, then it is not a rare case with classroom discourse. For example, Mercer et al. (1999) cite a number of research studies and suggest that the use of language in the classroom is often confused, unfocused and unproductive. Solomon (1998) puts forward some reasons why science teachers tend not to use discussion and argumentation as tools for teaching and learning, including lack of skill in managing the process and uncertainty as to its value.

4.7 How pre-service teacher PT15 used Newton's Second law equation while calculating mathematical problems in physics (Item 3.6.2)

Pre-service teacher (PT15) started by drawing a free-body diagram of a wooden box of weight of 100N that is placed on a metal ramp inclined at 30° to the horizontal and labeling all the forces acting (Figure 4.3). The math-in-physics problem (item 3.6.2 of PSAT) required that the pre-service teacher determine through calculation whether the wooden box is in a state of rest. First, PT15 wrote than her reason of choosing Newton's second law equation ($F_{net} = ma$):

“If there is acceleration calculated then we know that the box is moving.”

After deciding on what formula to use to solve this problem, she paused and remarked that she did not have a value for the normal force F_N for the equation, $f_s = \mu F_N$. She calculated the normal force using the Pythagoras theorem. Probably while she was evaluating what components constitute the net force in the equation she had constructed earlier, she realized that the *parallel component* of the weight of the wooden box should also be calculated [DAM level +7]; she then computed it and wrote this value in her diagram, next to her free-body-diagram-FBD (Figure 4.3).

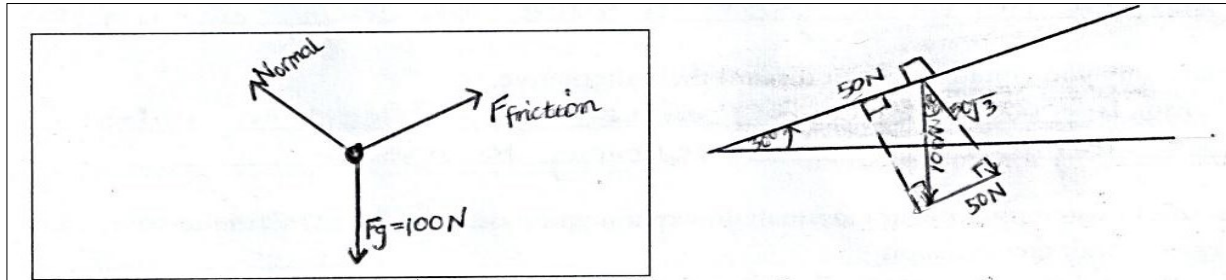


Figure 4.3 Physical representation of the problem (FBD) by PT15

In what followed, she had probably said to herself, I shall plug in the *parallel component* ($f_{g//}$) of the weight of the wooden box and the static friction (f_s) I calculated earlier into the equation ($F_{net} = ma$). Next, I subtract their difference, and after that I use the mass and multiply by the unknown acceleration (a) that I'm looking for [DAM level 6]. From there, I make the unknown acceleration a the subject of the formula with respect to the quotient of the value of the net force and the value of mass, and that would give me the acceleration of the wooden box ($a = 0.24m/s^2$). Figures 4.4 show all of her work.

| Choose a formula if applicable and explain why | Show calculation |
|--|--|
| $F = ma$ <hr/> If there is acceleration calculated then we know that the box is moving. | parallel component of weight $= 100 \sin 30^\circ$ $= 50 \text{ N}$ $f_s = \mu_s N$ $= 0,3(50\sqrt{3})$ $= 25,98 \text{ N up the slope}$ $F_{net} = ma$ $50 + (-25,98) = 100a$ $a = 0,24 \text{ m/s}^2$ $\therefore \text{The box is not at rest.}$ |

Figure 4.4 Pre-service teacher PT15's physics problem-solving

After working out the acceleration of the wooden box, she explained her thought process.

So the question asked me to determine whether the wooden box is in a state of rest and explain reasons that led to my solution, so I would say the "box is not at rest" [DAM level +7].

Limited research in problem solving has shown that solving a problem involves several types of mental tasks (Bing & Redish, 2009), such as creating representations of the problem as pre-service teacher PT15 has done (Larkin & Reif, 1979), recalling knowledge relevant to solving

the problem (Shin et al., 2003), keeping track of the problem goal (Sherin, 2006). But as we shall see in the next section, PT15 failed to monitor whether the solution that she obtained is consistent with other known information (Muallem & Eylon, 2010; Reif & Allen, 1992).

4.8 Holding misconceptions of physics principles alongside with correct mathematical calculations in 2D mechanics problems

Even though PT15 was correct to show through her calculations that the wooden box is not at rest, her thinking consists of many things that play a part in her misconception of physics principles above mathematics. As already explained, she started her calculation by making a claim “if there is acceleration calculated then we know that the box is moving.” Such an idea is evidence of a misconception; it is incorrect because it is based on faulty thinking or a fallacy in reasoning. Very briefly, a fallacy in reasoning is often referring to errors in reasoning, appeal, or language use that renders a conclusion invalid (Madsen, 2006). This is something I will return to later in this chapter.

Regarding the pre-service teacher’s misconception (PT15), it is interconnected with a number of reasons, but can be resolved with a sustainable framework of conceptual change and extensive practice (Limón, 2001). A possible reason could be that she perceived an object’s motion or movement dependent on acceleration (a). Another reason may be due to her lack of understanding of net force (F_{net}) and equilibrium.

Hodes and Nolting (1998) propose four types of problem-solving errors, and explain them as follows:

1. careless errors, which are mistakes made and could be caught automatically upon reviewing one’s work;
2. conceptual errors or mistakes made when the student does not understand the properties or principles covered in the subject matter/textbook or lecture;
3. application errors or mistakes that students make when they know the concept but cannot apply it to a specific situation or question; and

4. procedural errors when students skip directions or misunderstand directions, but answer the question or problem anyway.

Drawn from Hodes and Nolting (1998), the second and fourth errors represent the errors pre-service teacher PT15 had made during her problem-solving. Leinwand (2012) asserted that such misconceptions and those that still emerge can be addressed by ensuring our instruction probes students' understanding and provides them with opportunities to show and explain their reasons.

In pursuance of correct scientific notions about item 3.6.2, in which PT15 encountered a misconception, the item required that pre-service teachers should determine through calculations whether the wooden box is in a state of rest. The relationship between net force (F_{net}) and equilibrium is that, when an object is in equilibrium, the net force (F_{net}) acting on it is zero. The sum of the components of forces acting in the x -direction is zero and so is the sum of the components acting at right angles in the y -direction. In order to verify the arguments that led to the second and fourth errors made by PT15 according to Hodes and Nolting (1998), one would have expected the pre-service teacher to say: If the box is in a state of rest, the net force acting on it is zero ($F_{net} = 0N$). For this to be so, the net force in the y -direction is zero and the net force in the x -direction is zero ($F_{x_{net}} = 0$). As such, the box cannot move in the y -direction so ($F_{y_{net}} = 0$). This then is illustrated in Figure 4.5.

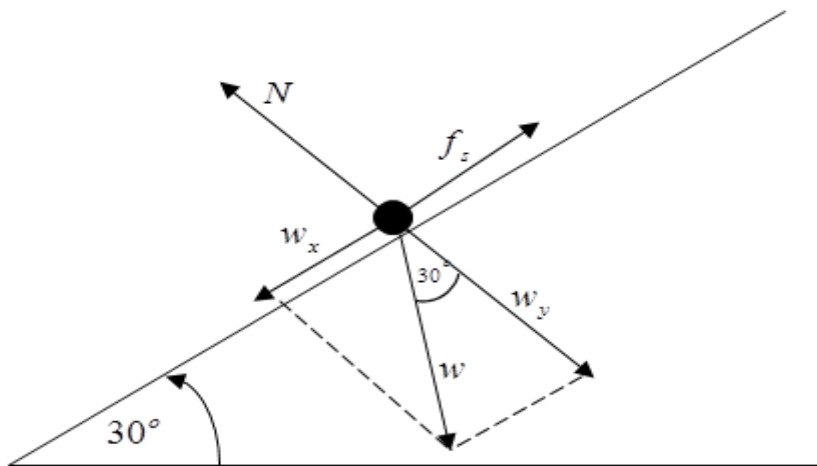
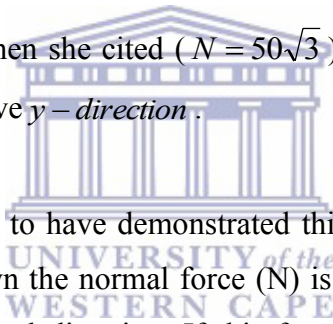


Figure 4.5 Free-body diagram of item 3.6.2

From Figure 4.5, net force in the x – *direction* shows there are two forces acting on the wooden box w_x and f_s , namely the component of the box’s weight down the slope and the frictional force up the ramp, $F_{net(x)} = w_x + f_s$. Along this dimension, an emphasis on dialogical argumentation in the present study is consistent with the goal of improving students’ scientific reasoning and proficiency in advancing, critiquing, justifying claims (Khun & Udell, 2003), and solving problems (Driver et al., 2000). It is evident pre-service teacher PT15 had a good understanding about this and had no problem recognizing, interpreting and computing the net force in the x – *direction* . She (PT15) had the ability to perform the mathematical calculations needed to show that ($w_x = w \sin \theta = -100 \times \sin 30^\circ = -50N$) down the slope. This then follows with the computation of the normal force in order to calculate the maximum static friction (f_s^{\max}). She also got this right, in that she showed that ($N = -w \cos \theta = -(-100) \times \cos 30^\circ = +86,60N$) in her calculation of static friction when she cited ($N = 50\sqrt{3}$). The positive sign tells us that the normal formal force is in the positive y – *direction* .



For the pre-service teacher (PT15) to have demonstrated this level of math-in-physics problem solving skills, she must have known the normal force (N) is the force between the wooden box and the surface acting in the vertical direction. If this force is not present the box would fall through the surface because the force of gravity pulls it downwards. Since static friction is present when the object is not moving and kinetic friction is present while the object is moving, the pre-service teacher interpreted this correctly. The box does not move. Thus, when the subsequent item of 3.6.2 asked pre-service teacher PT15 to explain reasons that led to the solution she obtained, she explained:

“The frictional force is bigger than that of the force of the box traveling down the slope.”

In the same line of thought, in account of what holds true in the context, if the box is at rest, the frictional force is less than or equal to the maximum static friction. In her final calculation of the vector sum of the $F_{net(x)} = w_x + f_s$, she obtained $F_{net(x)} = +24.02N$, where the correct answer was $F_{net(x)} = -24.02N$ showing the wooden box is moving down the slope. The positive answer she obtained did not bother her as she proceeded with finding acceleration.

Such errors fall in the ambit of first and third errors according to Hodes and Nolting (1998) discussed earlier. One possible reason why the pre-service teacher may have turned a blind eye to the positive answer she obtained on the vector sum of the x -component could be attributed to her assertion from the beginning where she stated “if there is acceleration calculated then we know that the box is moving.” There is no doubt that calculating acceleration or arriving at an answer of some sort is all that mattered to her. For that reason, she paid less attention to what the $F_{net(x)} = +24.02N$ stood for. To this end, we know if the net force is non-zero and acts down the ramp, the box will not remain at rest.

4.9 PT28’s case: Mathematical competencies and other conceptions for problem-solving in physics

It is surprising that PT28 showed a strong inclination in mobilizing math-in-physics skills as he prefers to keep constants as symbols all the way to the end of his calculation rather than to put numbers in at the beginning. This, I argue, as have some others (such as Jewett, 2008; Heller et al., 1992; Kim & Pak, 2002; Redish, 1999), that the specific errors in students’ thinking are not always detected unless there are follow-up questions. Because I found the approach used by PT28 uncommon among the pre-service teachers, I decided to bring this matter up during the class presentation. During small group presentation, PT28 was asked: why do you prefer to keep constants as symbols in your calculations rather than to put numbers in at the beginning?

PT28 responded...by so doing I could see the equation as relationships among other variables in the equation.

What followed in the work of PT28, was through a step-by-step method and visual information from the free-body diagram he drew, he became aware of the exterior features of the quantity he was calculating. Thus, he found a pattern by which to predict a general case for the variable, tension force (F_T). But he did not show enough evidence of exhibition of vector signs or choosing direction. After exploring the steps he undertook separately, he was able to generalize this process and to extend his generalization into correcting the algebraic error [DAM level +7].

| Choose a formula if applicable and explain why | Show calculation |
|--|---|
| $W_{\parallel} = W \sin \theta$ $N = W_{\perp}$ $W_{\perp} = W \cos \theta$ $F_s^{\max} = \text{max. static friction}$ $\mu_s = \text{Coefficient of static friction}$ $\therefore F_s^{\max} = \mu_s N$ $N = \text{Normal force}$ <hr/> <u>We need to find the components of weight, Normal force = weight perpendicular (W_{\perp})</u> <hr/> <u>And also find friction. If All forces := Net force of 0 then object is @ rest.</u> | $W_{\parallel} = W \sin \theta$ $W_{\parallel} = 100 \sin 30^\circ$ $W_{\parallel} = 50 \text{ N}$ $W_{\perp} = W \cos \theta$ $W_{\perp} = 100 \cos 30^\circ$ $W_{\perp} = 86,60 \text{ N}$ $\therefore N = W_{\perp}$ $\therefore N = 86,60 \text{ N}$ $F_s^{\max} = \mu_s N$ $F_s^{\max} = (0,3)(86,60)$ $\therefore F_s^{\max} = 25,98 \text{ N}$ \therefore The wooden box is not at rest, but moving down the slope. |

Figure 4.6 PT28's approach to math-in-physics problem-solving

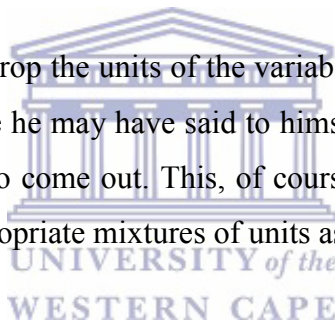
In exploring his steps he tried to extend a critical look at all the calculations he had performed, he restricted his solution to the problem with the constant units he kept from the beginning of his problem-solving (see Figure 4.6). I believe this is not only just a way to calculate a result, but it is a way to generate a whole ensemble of results; not only the one you are currently calculating, but all possible situations with the same math-in-physics, but different values for the parameters. This is a dramatic shift of outlook and one that I believe could help pre-service teachers master math-in-physics problem-solving.

The difference between PT28 and pre-service teacher PT1's approach in solving mathematical problems in physics can be summarized in this manner: Unlike PT28's approach, PT1 at the beginning of his calculation plugged and manipulated numbers into his equation as soon as he knew the variables. This made the equation look more familiar to him. However, doing this led to difficulties. For the context of mathematics used in physics problem solving, PT1's manipulation of symbols as an approach could not provide him with the procedural fluency or mathematical reasoning and thinking that often accompanies successful approaches reported in the literature (Bing & Redish, 2009; Junkins, 2007; Redish, 2005). Evidence from his work showed several cancellations of his earlier steps (see Figure 4.7).

| Choose a formula if applicable and explain why | Show calculation | |
|--|--|--|
| $V_y = F \cos \theta$ $V_y = F \sin \theta$ <p>Because components are represented by projection of vectors onto each line. V_x parallel to line at θ to line of action of the force, V_y perpendicular to the line</p> | <p>Vertical V_y</p> $\begin{aligned} \text{Vertical } y &= F \sin \theta \\ &= m_y g \sin \theta \\ &= 50 \times 9.8 \sin 50^\circ \\ &= 375.36 \text{ N} \end{aligned}$ $\begin{aligned} \text{Vertical } y &= F \sin \theta \\ &= 400 \sin 50^\circ \\ &= 306.42 \text{ N} \end{aligned}$ | <p>Horizontal V_x</p> $\begin{aligned} \text{Vertical } x &= F \cos \theta \\ &= M_y \cos \theta \\ &= (50)(9.8) \cos 50^\circ \\ &= 314.97^\circ \end{aligned}$ $\begin{aligned} \text{Vertical } x &= F \cos \theta \\ &= 400 \cos 50^\circ \\ &= 257.12 \text{ N} \end{aligned}$ |

Figure 4.7 PT1’s approach to math-in-physics problem-solving

Pre-service teacher, PT1 tends to drop the units of the variables after plugging in the numbers in the equation. Probably at this stage he may have said to himself I will put the units in at the end since I know how the units have to come out. This, of course, loses the advantage of using the units as a check on errors or inappropriate mixtures of units as PT28 did.



A study conducted by Bing and Redish (2009) gave a clear understanding of how we can make sense of PT28’s work. In their study they examined different ways in which students frame the use of mathematics in physics. They found that even though students had knowledge and skills of how to apply certain mathematics in order to solve a problem, they often got stuck in a frame that would not lead them to the correct answer. If, for example, students failed to solve a problem due to the wrong mathematical approach, they were unable to map the physics concepts to the appropriate math without assistance.

In another instance, PT20 has a naïve mathematical representation consisting of the equation relating the variables in the problem that must be solved to produce the final answer. It is, again, one of the main issues I have highlighted elsewhere in this chapter. Even for most successful problem solvers in the study there seems to be a lack of basic conceptual understanding of physics mechanics of the PSAT items tested. One common explanation is that pre-service

teachers' everyday experiences seem to contradict physics principles. Some of the commonsensical explanations provided by the pre-service teachers which revolve around their everyday experiences collaborate with the earlier findings by Wandersee et al. (1994), which includes the use of intuitive rules, prior experience, use of language, and even instruction. Such conceptions are remarkably resistant to change using conventional teaching methods (Wandersee et al., 1994). On this troubling issue, Hynd et al. (1997) suggest that through the use of texts that include arguments, the refutation of common misconceptions can be achieved.

4.10 Item 4: A continuous force is needed for continuous motion – Pre-service teachers' responses

This item asked pre-service teachers whether they agree or disagree with the claim. Of the forty pre-service teachers who responded to the item at observation -O1, twenty-eight of them “agreed” and twelve “disagree.” At observation -O2, nineteen of those who had agreed changed their minds to disagree, pushing the number of those who disagree to thirty-one, with only nine who maintained their initial stances at observation (O1). At observation O2, thirty-four of them chose to disagree, with only six maintaining their initial stances, that is, agreement. Pre-service teachers' arguments during the small group discussion in which they were asked to present their views tend to be grounded on another claim they had made:

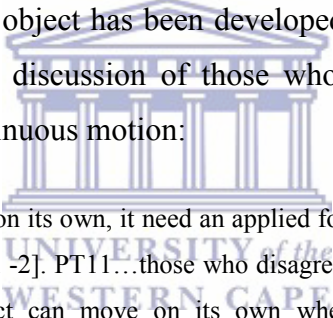
Everything that moves will eventually come to a stop ... [is this always the case and why do you think this, even in outer space?] At observation-O1, majority of the class replied “yes....we all know being at rest is the “natural” state of motion of all objects” {CAT stage -1}. PT15 added, something cannot move if there is no force acting on it [DAM level 3 & 4]. [Can you elaborate more on this?]...ok, I think so, because often you need an initial force in order for something to move [DAM level 6]. At observation O4, majority of the class had changed their views to “no.”

Given pre-service teachers' grounds, it is easy to think that the origin of their misconception is about the claim that a continuous force is needed for continuous motion, and that this is somewhat deeply rooted on the grounds they provided. A direct consequence of their later claim is that “everything that moves will eventually come to a stop.” While this is true, if you are, for example, pushing a grocery trolley in a shopping mall, again this is only because there is friction involved: the force you apply to keep an object moving is only to counteract the frictional force.

If you were to throw a rock into outer space, it would travel with a constant velocity forever, unless it hits something, of course. This is because space is empty, and there would not be any frictional force acting on that rock.

In the same vein, every description of the position or movement of an object, say, in space is based on the specification of the point on a rigid body (body of reference) with which that object coincides. This applies not only to scientific description, but also to everyday life. It is not necessary here to investigate further the significance of the expression “coincidence in space.” This conception is sufficiently obvious to ensure that differences of opinion are scarcely likely to arise as to its applicability in practice.

On the basis of the foregoing discussion, we are able to see the manner in which a refinement of the conception of movement of an object has been developed. Here are some of the excerpts in what followed in the small group discussion of those who agreed with the statement that a continuous force is needed for continuous motion:



PT8: ...an object does not move on its own, it need an applied force, for example a box on a table {CAT stage +1} and [DAM level -2]. PT11...those who disagree with the statement probably did so because they think an object can move on its own when there is no force behind its motion.[Don't you think they could be right, say, in the absence of friction?]. .he goes on to say, their alternative is scientifically incorrect base on Newton's law that says when a force is exerted on an object, the object will move in the direction of that force provided there is no greater opposing force [DAM levels 3, 4, -5, 6 & -7]...and when the opposing force is greater, what happens?]. . . (No response) [DAM level -1] and {CAT stage 2}.

There is reference to Newton's law that the pre-service teacher PT11 used to back his argument. In the face of such evidence, misconception exists. For example, while he tried to create a web of knowledge with the formal argument, he failed to clarify his stance on the issue at stake. His understanding of the effects of forces on a moving object conform neither to verifications of Galileo's understanding of opposing force or friction force, nor to Newton's second law of motion. If one comes to the rescue of pre-service teacher PT11, perhaps what he was trying to say in the first part of his argument is that since a force is responsible for moving an object, then regardless of context, without a force, the object will stop moving. Whether or not this comes

close to what he was thinking or trying to say, it falls short of what we now know today about the effects of forces as espoused by Galileo and those after him, such as Isaac Newton.

As a modification of the views, I presumed that what pre-service teacher PT11 was probably thinking about does not become necessary until we come to deal with the misconceptions of the effects of forces on the motion of an object. For the time being however, we shall assume its correctness. In short, let us assume that the simple law of motion, Newton's First Law, is justifiably believed by every learner at school. Who would imagine that this simple law has plunged the conscientiously thoughtful physicist into the greatest intellectual difficulties? Let us consider how these difficulties arise.

Misconceptions about the effects of forces on the motion of an object or (a body) can be traced back to the time of the Greek philosopher, Aristotle, who lived approximately 3 300 years ago. During Aristotle's lived experience, he thought that a force is necessary to keep an object moving. He believed that the speed of an object depends on the strength of the force, as was the case with some pre-service teachers in the study. Indeed there are everyday life examples that can quantify what both Aristotle and some of the pre-service teachers in the study thought.

For example, if you consider the motion of a chair that you push across the floor, it is easy to agree with this. As soon as you stop pushing the chair, it slows down and comes to a stop. For nearly 1900 years, Aristotle's ideas were accepted without serious criticism. This is because at his time, and long afterwards, very few scholars and scientists conducted experiments to see if observations would support their theories. However, it took centuries to understand this and it is an interesting example of the progress of scientific method and theories of another philosopher by the name of Galileo Galilei who challenged Aristotle's ideas, which had at the time gained traditional merit.

Interestingly, he (Galileo) realized that frictional forces play a role in the motion of an object. To reduce the effect of friction, he rolled a ball along a smooth horizontal surface. He observed that the ball slows down only very gradually. He then concluded that a moving object tends to keep on moving in a straight line.

Along the same line of observation, he saw that if there is no friction, an object does not need a force to keep it moving at a constant velocity. This refined notion then provides correct scientific explanation to item 4 under discussion. This whole notion was later made simpler by Isaac Newton. For example, Isaac Newton built on Galileo and others' ideas, and formulated his theories mathematically in his treatise known as the *Principia*. To explain the motion of an object, Newton considered the net force resultant of all the forces acting on an object, which includes frictional forces.

One other issue that deserves close attention was the example in the backing pre-service teacher PT8 gave. PT8 believed that “an object does not move on its own; it needs an applied force, for example a box on a table.” The example he gave about “a box on a table” is an excerpt from his everyday science life (Scott et al., 1992). Underscoring this point, Sherin (2001) proposes the existence of knowledge structures which link to intuitive conceptual ideas.

By “intuitive” concept ideas, he meant ideas that are informally drawn from everyday knowledge, that make quick and immediate sense and that do not seem to require further explanation. In the case of PT11, probably the latter holds true. If so, then intuitive concept ideas were evident in the non-response of PT11 when asked to explain what happens if the opposing force is greater than the applied force. Using Newton's second law incompletely or incorrectly, he stated in support of his point that he saw no need for further explanation.

4.11 Small Group presentation – Item 6 on gravity: *A hammer and a feather*

Figure 4.8 shows an animated portrait done by me to illustrate how this item was debated and discussed by the pre-service teachers in a DAIM setting. Figure 4.8 does not only portray how the pre-service teachers modeled conceptual change through the nature of argumentation, but it is also an illustration that accounts for Aristotle's incorrect view about gravity (that heavy objects fall faster than light objects).

Although in a commonsensical notion, Aristotle's assumption sounds reasonable, it does not hold true in all contexts. What made his notion of gravity wrong was that his view is context-independent – it is a nonspecific notion, which means his assumptions apply to all contexts.

This view held by Aristotle dominated scientific thinking for nearly two thousand years until it was falsified by Galileo's experiment. This is why such conceptions and those I discuss earlier are sometimes resistant to change using conventional teaching methods (Scott et al., 1992; Wandersee et al., 1994). In approaching conceptual change, Galileo demonstrated that a metal ball fell at the same rate as a feather if air resistance is removed. In argument (debates and discussion), conceptual fruition was gained through innovation and selection. An example of such debate and discussion done by the pre-service teachers in a DAIM setting has been animated, (see Figure 4.8).

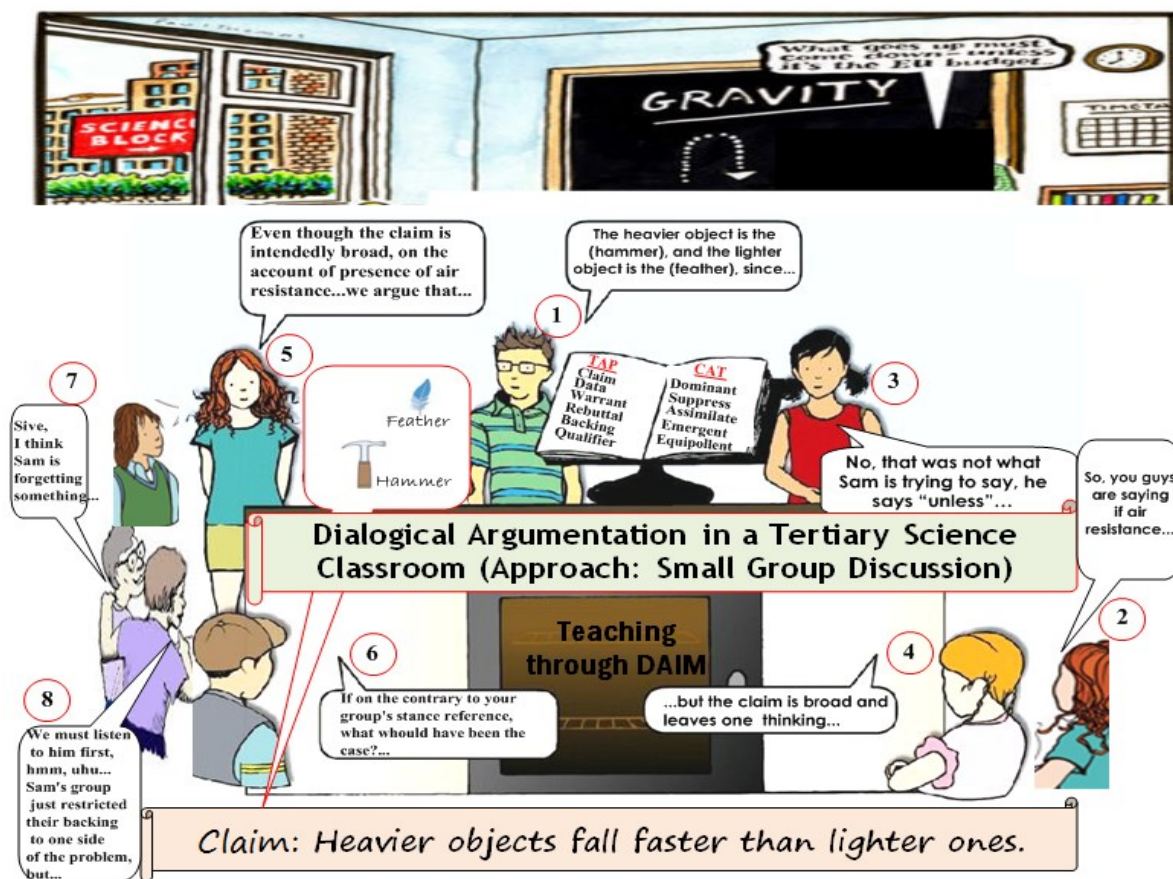


Figure 4.8 Animation of debate and discussion in a DAIM setting for the study

4.11.1 Gravitational influence on a hammer and a feather

An analysis in terms of (PSAT item 3.6) focuses on the moment-to-moment cognitive shifts observed in pre-service teacher PT5's reasoning. Pre-service teacher PT5 who sat in the

discussion (as depicted in animated Figure 4.8) was selected from group G to assess her understanding of the influences of the force of gravity on a hammer and a feather (item 3.6).

PT5 has just explained how she arrived at her solution for math-in-physics problem (item 3.4) and is so dense that heavy objects fall faster than lighter objects. Wanting to explore this further, I bring up the case of the force of gravity's influence on “a hammer and a feather”. When I ask her whether a hammer will hit the ground first before the feather if both are released at the same height and time in the absence of air resistance, PT5 responds that the hammer will hit the ground first {CAT stage -1} [DAM level +1]. I then asked her why she thought that and she responded without a second thought: “It’s obvious; I can demonstrate it if you want to.” [DAM level -2]. The conversation continued, and when the next opportunity arose for PT5 to justify a claim, she made a blanket statement stating, “Can I demonstrate it for you, sir.”

So far in the discussion, she is relying on authority in her explanations, quoting rules and facts, but negating important information in the problem statement, that is, the “absence of air resistance”. After I prodded her to give “any explanation you find,” PT5’s reasoning undergoes a shift. She gives a more detailed, more conceptual account of conditions under which the hammer and a feather could hit the ground at the same time and at different times. Once she has had time to think, she puts together the important missing part of the problem statement that initially led her to wrong reasoning. So when I asked her, “why didn’t you consider the absence of air resistance in your first explanation?” she bent her head, took a deep breath before replying, “I had ignored the last part of the problem statement.” {CAT stages -1 & 2}. Why? I asked, and she replied, “I had thought it doesn't matter, but when you prodded me to think of my reasons, I then gave it a careful thought” [DAM level +7].

The cognitive shift I care about in PT5’s reasoning concerns the types of explanations she gives. She began by quoting facts [DAM level 3]. Implicit was PT5’s epistemic interpretation of her situation and my intentions for modeling conceptual change through innovation and selection in a dialogical argumentative context. “What is the nature of the knowledge at play here?” – my apparent dissatisfaction concerned PT5 initially quoting facts. Subsequently the “any explanation you find” prompt caused PT5 to reinterpret the activity. She came to see my questions as

prompts for her to keep thinking and to re-evaluate her initial stance. Even though she initially showed confidence in her stances by adding, “Can I demonstrate it for you?” she is less sure of her omission of the “absence of air resistance,” contradicting the facts she later quoted. But with continuous prodding she sees this uncertainty as permissible for her to re-evaluate her initial stances. Her cognitive shift shows: “she reconstructed her stances, and supported her quoted facts with valid reasons.” It is thus conceivable that PT5 had gone from a commonsensical knowledge dominant position {CAT stage -1} to suppressing her ideas, in that her everyday experience was more convincing than scientific orthodox {CAT stage 2}. But as prodding continued she started to re-assess her initial stance which led her provide an implicit answer [DAM level +7]. This then led her to consider a more persuasive idea {CAT stage 3}.

One can assume that the prodding “What kind of knowledge is at play here, any explanation you can find?” led PT5 to bring different subsets of her knowledge store to bear upon my questions. The cognitive exercise of PT5 confirms Kuhn's (1991) expression that rebuttals are evidence of the development of cognitive argumentation skills. In other words, rebuttals indicate the quality of arguments in that they challenge participants (in this case PT5) to evaluate the validity and strength of her argument (Erduran, 2007). Put simply by Erduran et al. (2004), the more the rebuttals (prodding in this context), the higher the quality of that argument.

I now turn to a more detailed account of other moment-to-moment cognitive shift processes observed among other pre-service teachers, beginning with an overview of epistemic resources. In the same item excerpts extracted from pre-service teacher PT9 reveal the following:

The first time me and my classmates responded to this same item, I agreed that a hammer will hit the ground first before a feather if both are being released from the same height and at the same time in the absence of air resistance. But, after we went through the new method, argumentation, and Lindile (PT33), Megan (PT 15) and Karriem (PT16) from other groups convinced me that both hammer and feather will hit the ground at the same time in the absence of air resistance, I now agreed with them {CAT stages 3 & 5} and [DAM levels +5 & +7].

According to the Contiguity Argumentation Theory (CAT) as espoused by Ogunniyi (2007a & b), when a conflict arises in the mind of a student as a result of being exposed to school science (in this case, science construct), the CAT suggests that a sort of “internal argument” or

“conversation” ensues within him/her at the micro-neuro-psychical level between competing schemata in the working memory where consciousness in an individual is assumed to be most active (Le Doux, 1999; Ogunniyi, 1997, 2000). The present context involved PT9’s claim and counter-claim (rebuttal) that a hammer will hit the ground first before a feather if both are released from the same height and at the same time in the absence of air resistance. He later changed his view due to socio-persuasion. In terms of the CAT, justification of PT9 carries the same banter pregnant meaning with conceptual fruitfulness, which occurs only when a person’s conception has met with dissatisfaction (Posner et al., 1982). In this regard, conceptual change is seen as an evolutionary process in terms of ‘innovation and selection’ as espoused by Toulmin (1972), hence, the interpretation of evidence, and the validity of knowledge claims are at the heart of scientific orthodoxy.

4.12 Frequency of Instances: Individually constructed, written and evaluated arguments

(Item 5)

The analysis of item 5 of Appendix C involves the use of different levels of arguments (CAT and DAM) to investigate the evolution of the dialogic argumentation produced by the pre-service teachers throughout the discussion. The detection and interpretation is based on the existence of the relation between the variables represented by the dimensions of the Tables 4.3 and 4.4. A very meaningful way to interpret the levels of argument produced by the pre-service teachers as they construct, write and evaluate arguments is provided by the examination of the size of respondents for each cell and their corresponding percentages. Moreover, apart from the quantitative analysis of discussions, a qualitative analysis is used to substantiate the statistical findings. Pre-service teachers responded to this item: “*An object is hard to push because it is heavy*” as depicted in Figure 4.9.



Figure 4.9 An object is hard to push because it is heavy

4.12.1 Item 5.1: Do you agree or disagree with this notion?

Item 5.1 expects pre-service teachers to state whether they agree or disagree to the claim “An object is hard to push because it is heavy.” According to Downing (2007), pre-service teachers’ responses do not include grounds and there are no rebuttals. The level of such claims to knowledge with no evidence is classified as [DAM levels 1& 2]. Here are some of examples of pre-service teachers’ responses:

34. PT6: I agree. [DAM levels +1 & - 2]
35. PT13: I think so. [DAM levels +1 & - 2]
36. PT17: I agree. [DAM levels +1 & - 2]
37. PT9: I disagree. [DAM levels +1 & +2]
38. PT2: Agree. But sometimes, not always the case. [DAM levels +1 & - 2]

4.12.2 Item 5.2: If you agree, state why. If you disagree, state why.

39. PT6: I agree. Because the heavier an object is, the more difficult it is to push. [DAM levels +1 & - 2] and {CAT stage -1}.
40. **Prodding:** Why do you think this?
41. PT6: It is a common sense, obvious. For example, think of pushing a big box and a small one. [DAM levels +1 & - 2] and {CAT stage -1}.
42. PT13: I think so, for example a truck is bigger than a normal car, so it is more difficult to push a truck than a car. [DAM levels +1 & - 2] and {CAT stage -1}.
43. PT17: I agree. Because a heavy object will always be hard to push than a lighter object. [DAM levels +1 & - 2] and {CAT stage -1}.
44. PT9: I disagree, I don't think so, I've forgotten the term to explain why object are hard to push. [DAM levels +1 & +2] and {CAT stages 2& 3}.
45. PT18: I think what Sipho (i.e. PT9) is trying to say is Inertia. [DAM level 4] and {CAT stage +1}.
46. PT9: Yeah, that's correct, it is called “inertia”, you're right Soraya (i.e. PT18). [DAM levels +1 & +2] and {CAT stages +1, 3 & 4}.
47. PT2: Agree. But sometimes, not always the case. [DAM levels +1 & - 2]
48. **Prodding:** Can you elaborate more?
49. PT2: I think the surface plays a role in determining whether a heavy object is hard to push or not. [DAM levels +1 & + 2] {CAT stage 4}.
50. **Prodding:** You mentioned the “surface”, what role does the surface play in the context?
51. PT2: If the surface is rough, then there is bigger frictional force, the object will be hard to push whether the object is heavy or not. [DAM levels 4 & 6]
52. **Prodding:** Suppose we have smooth “surface”, would you agree or disagree that an object is hard to push because it is heavy.
53. PT2: A heavy object will be hard to push than a light object. [DAM levels +1 & -2] and {CAT stage-1}

The second item (5.2) includes discussions containing claims or counterclaims with grounds and no rebuttals. In the following example there is an initial claim (“an object is hard to push because it is heavy”). Then, after the claim there follow grounds (“reasons for agreeing or disagreeing”).

As the pre-service teachers' argumentation contains claims with grounds, and no rebuttals, it is classified as [DAM levels 3–7].

4.12.3 Item 5.3: One of your classmates may disagree with you. What might their alternative be?

54. PT6: *They don't need to agree with me.* [DAM level – 5]
55. PT13: *I will give them an example; maybe ask them to push the class desk while I'm sitting on it, and after try pushing it empty, then they must compare the two examples.* [DAM levels 3, 4 & -5] and {CAT stage -1}
56. PT17: *My classmate might say, what "Sipho and Soraya" (i.e. PT9 & PT18 as in 45 and 46 lines of arguments) said earlier.* [DAM levels +1, -2 & +5] and {CAT stage 3}
57. **Prodding:** So are you somewhat agreeing with Sipho and Soraya?
58. PT17: *Eish man!*
59. **Translation:** ("Eish man" is one of the South African local dialects. In "IsiXhosa" it's a state of uncertainty). Translation varies.
60. PT17: *I think they made sense, so I agreed with them.* [DAM level +5] and {CAT stage 3}
61. PT9: *I stand by my stance; an object is hard to push because of its inertia. So it is possible for another colleague to think an object is hard to push because of its weight. This is easy to think.* [DAM levels 3, 6 & +7] and {CAT stage +1}
62. PT18: *When you think of it outside science context, one might think it is true, so it is possible for others to think so, as for me, it is because of its inertia.* [DAM levels 6 & +7] and {CAT stages 2 & 3}
63. **Prodding:** Soraya, you are the first to use the term "inertia" when you reminded Sipho while he was searching for a correct scientific term to describe his notion. What do you think inertia is?
64. PT18: *I'm not so sure, but I can try...it is the tendency of an object to resist change. It acts as a force, but not a force.* [DAM levels 4 & 6] and {CAT stage +1}.
65. **Prodding:** Sipho, what Soraya said is it what you had in mind before?
66. PT9: *Yes! I knew it, but could not recall it.* [DAM level +5] and {CAT stage 3}
67. PT2: *I think another student might think it is not so, I don't know what his or her reason would be, so I can't really say.* [DAM level -2]

4.12.4 Item 5.4: Explain why you would accept or discard your classmate's alternative on (item 5.3).

The fourth item (5.4) includes discussions containing claims or counterclaims, with grounds and only a single rebuttal that challenges the thesis of the claim [DAM levels 4 – 7]. Here, a pre-service teacher might propose a rebuttal which includes a claim opposing the initial claim.

If there are no grounds included in this rebuttal, it is a rebuttal that challenges the thesis of a claim. As a result, this discussion is classified as levels 4-7 according to Downing (2007). Taken together, critics of these levels of arguments 4-7 are harmonized with the five stages of CAT {stages 1-5} as ideas are likely to emerge, dominate, be assimilated, be suppressed or become competing.

68. *PT6: I listened to what Soraya, Siphon and others are saying, but why do we always pull light objects and not push them? It is because the heavier the object is, the more difficult it is to push it. Guys, I'm talking about what we do and not what science says. So I say objects are hard to push because of its weight. {CAT stages -1 & 2} and [DAM levels -5 & -7]*
69. *PT13: I see no reason to say further because what Nosisa (PT6) is saying is what I have in mind. So I disagreed with Soraya, Siphon and those who agreed with them. {CAT stages -1 & 2} and [DAM level -5]*
70. *PT17: We have tried in our group to sketch a free body diagram, we saw from our diagram that it is not the weight of the object that makes it hard to push, but its inertia, what Soraya and others were saying. {CAT stages 2, 3 & 4} and [DAM levels 4, +5, 6 & +7]*
71. *PT9: I still say, an object is hard to push because of its inertia. {CAT stage +1}*
72. *PT18: Another example I forgot to mention is...I think frictional force has a linked to an object's inertia. It makes sense to think so. [DAM level 4]*
73. **Prodding:** Soraya, I commend your constant thinking and generation of ideas, now can you elaborate more about how frictional force is linked to an object's inertia?
74. *PT18: Ok! I thought so because if you think about it in terms of connection, what they have in common, frictional force resist an object's direction so is the inertia. That's what I think. [DAM levels 6 & +7]*
75. *PT2: I didn't agree with Soraya before, but having thought about her idea of linking frictional force and inertia, I think she is correct. [DAM levels +5 & +7]*
76. **Prodding:** So do you agree that an object is hard to push because of its inertia?
77. *PT2: Yes, I agree. {CAT stages 2 & 3}*

Table 4.2 Distribution of pre-service teachers' levels of arguments gauged by (DAM)

| Level of Dialogical argumentation DAM | Positive attributes (N) | Negative attributes (N) | Positive attributes (%) | Negative attributes (%) |
|---------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Level ± 1 | 33 | 22 | 67.5 | 32.3 |
| Level ± 2 | 41 | 27 | 45.3 | 36.3 |
| Level 3 | 29 | – | 17.5 | – |
| Level 4 | 22 | – | 11.3 | – |
| Level ± 5 | 12 | 19 | 12.5 | 30.1 |
| Level 6 | 10 | – | 14 | – |
| Level ± 7 | 16 | 22 | 19.44 | 24.6 |

4.13 Distribution of pre-service teachers' levels of argumentation

Table 4.2 shows the distribution of pre-service teachers' dialogic argumentation by level as regards all group discussions (a total of 44 episodes of discussions). It emerges that the highest percentage of pre-service teachers' discussions belongs to level -2 (36.8%), and 32.3 percentages at level -1 . The percentage of pre-service teachers' discussions at DAM levels $+1$ and $+2$ (67.5% and 45.3% respectively) is also considerable. There seems to be a lower percentage of discussions classified at DAM levels 3, 4 and $+5$ (17.5%, 11.3% and 12.5% respectively). There are few discussions classified at DAM levels -1 , -2 , -5 and -7 (17.5%, 7.5%, 2.5% and 5% respectively).

Table 4.3 Distribution of pre-service teachers' categories of arguments gauged by the CAT

| Stage of Dialogical argumentation CAT | Positive attributes (N) | Negative attributes (N) | Positive attributes (%) | Negative attributes (%) |
|---------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Dominant: Stage ± 1 | 36 | 42 | 54 | 46 |
| Suppressed: Stage 2 | 29 | – | 48 | – |
| Assimilated: Stage 3 | 38 | – | 52 | – |
| Emergent: Stage 4 | 22 | – | 36 | – |
| Equipollent: Stage 5 | 13 | – | 22.5 | – |

As can be seen in Table 4.3 pre-service teachers' correct scientific knowledge was dominant at CAT stage $+1$ (46%) and commonsensical knowledge was dominant at CAT stage -1 (54%). Notions held by pre-service teachers were suppressed at 48% CAT stage 2. As more rebuttals ensue, ideas held by the pre-service teachers were assimilated at 52%, CAT stage 3.

Retaining of notions stood at 48%. This effect may be attributed to the scaffolding of pre-service teachers' dialogic argumentation skills.

Furthermore, at observation O2, it emerges that notions held by pre-service teachers were suppressed by 45%, emergent by 36% and equipollent by 22.5% in small group discussions classified at DAM levels +2, 4 and +5 respectively. However, pre-service teachers' commonsensical knowledge, dominant at 54% at observation O1 reduced to 41% at observation O2. A slight cognitive shift emanated from notions being assimilated or put in another way. Such a cognitive shift view from conceptual change could have been rooted in what Hewson (1999) calls conceptual exchange.

In the same line of thought it might be right to say pre-service teachers must have been dissatisfied with their existing notions as rebuttal increases. If such holds, it must then be the orientation of conceptual ecology that enunciated conceptual fruitfulness of notions classified in DAM levels +2 and 3 (7.5% and 12.5% respectively) and increased percentages of discussions classified in DAM levels 4, +5, 6 and +7 (27.5%, 17.5%, 15.0% and 20% respectively). In addition, there was a statistically important relation between the levels of pre-service teachers' dialogic argumentation and their performances on the use of the nature of arguments to solve mathematical problems in physics ($\chi^2 = 12.67$ $df = 2$ $p < .001$). This relation may be attributed to the following tendencies of tables (see Tables 4.3 and 4.4).

4.14 Interpretative Commentary

Pre-service teachers PT9 & PT18 provided justifications that are scientifically oriented and acceptable (see lines 44-46 of arguments). It emerged that while rebuttal ensued, pre-service teacher (PT2) invoked a fresh perspective to align and substantiate his ideas, in that he claimed the "surface" in which the object moves plays a role that makes the object hard to push (see lines 47-53 of arguments). When asked to elaborate more on this notion, he says:

I think the surface plays a role in determining whether a heavy object is hard to push or not. [DAM levels +1 & + 2] {CAT stage 4}. If the surface is rough, then there is bigger frictional force, the object will be hard to push whether the object is heavy or not. [DAM levels 4 & 6]

This notion he held is scientifically oriented and acceptable, however, in the face of such a new assertion, he insisted an object is hard to push because it is heavy (see line 53 of argument). In line 49, he asserted the notion of “surface” which he later on linked to “frictional force” in line 51.

In the foregoing case pre-service teacher PT2 is somewhat correct; the frictional force opposing the motion of the object is equal to the applied force, but acting in the opposite direction. This frictional force is called static friction. When we increase the applied force (push harder), the frictional force will also increase until the applied force overcomes it. This frictional force can vary from zero (when no other forces are present and the object is stationary) to a maximum that depends on the surfaces. When the applied force is greater than the frictional force, the object will move. The frictional force will now decrease to a new constant value which is also dependent on the surfaces. This is called kinetic friction. In both cases the maximum frictional force is related to the normal force.

It is also possible to think that despite PT2's effort to address the problem item, the construction and evaluation of his new assertion did not lead to conceptual dissatisfaction as in line 53 of his arguments. But, with socio-persuasion through small group activities, PT2 had his view changed after he underwent conceptual ecology tailored by his peer PT18, Soraya by name. This then lent itself to assimilation {CAT stage 3} as evidence of conceptual exchange (Hewson, 1999).

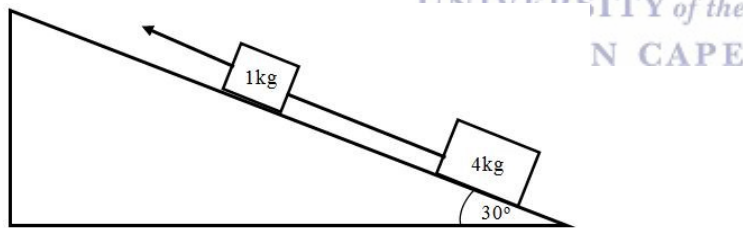
Still in the same item, an object is hard to push because it is heavy. Most pre-service teachers did not blink a second before giving their responses. For example, pre-service teachers PT3, PT6 and PT17 considered the statement as a commonsensical notion, something obvious to their everyday discourse (see lines 34-43 of arguments). Indeed, it sounds commonsensical. No wonder their responses were constructed in the face of what they perceived as “obvious.” This is one of the most common misconceptions because it is something we see and feel every day as has been reported by researchers studying students' misconceptions (Hutchison & Hammer, 2010; Pfundt & Duit, 2006; Scott et al., 1992).

As all this shows, while a heavy object is really hard to push, this is not because of its weight, but because of its inertia or mass as pre-service teacher PT18 (Soraya) correctly said. Inertia is an object's resistance to change in motion. It is important to note that inertia is resistance to "change motion" rather than just motion itself. This, I believe must have contributed to some of the pre-service teachers' (PT6, PT9, PT17) resistance and dissatisfaction with their pre-existing ideas (see lines 68-71 of arguments) (Wandersee et al., 1994).

4.15 How pre-service teachers demonstrated their argumentation skills during a group presentation on math-in-physics problem-solving

Problem statement (Item 4.6):

A block of mass 1 kg is connected to another block of mass 4 kg by a light inextensible string. The system is pulled up a rough plane inclined at 30° to the horizontal, by means of a constant 40N force parallel to the plane as shown in the diagram below. The magnitude of the kinetic frictional force between the surface and the 4 kg block is 10N. The coefficient of kinetic friction between the 1 kg block and the surface is 0,29. Calculate the Tension in the string connecting the two blocks:



The reader familiar with the physics of this item 4.6 (Appendix C) will recognize an attempt to get the pre-service teachers to see how Newton's second law that says ($F_{net} = ma$) can be translated into ($F_{net} = \sum F = F_A + f_f + Fg_{//} + T_f$). Not all the pre-service teachers in this discussion recognized the point of the problem from the beginning.

During this episode, pre-service teachers PT3, PT9, PT23 and PT37 tried to decide in their group if the applied force F_A should be the same along the opposite direction, that is, with $F_{g_{//}}$, f_f and T_f . The pre-service teachers are standing in front of the class with their poster containing all the

relevant and irrelevant equations and diagrams. In some research, equations are treated either explicitly or implicitly as computational tools, devices to find unknown values from known values through symbolic and numeric manipulation. This is true of the problem-solving procedures in the works of Heller et al. (1992), Huffman, (1997), Van Heuvelen, (1991a) and of studies on how successful problem solvers use mathematics (Dhillon, 1998; Taasoobshirazi & Glynn, 2009).

In this section I focus on the nature of arguments each pre-service teacher in their small group (for example, group H) offers in relation to math-in-physics problem-solving. Here are some excerpts from arguments as they unfolded:

78. PT3: *First, here is our equation which we think is correct.*

79. **Prodding:** How did you create or construct the equation? Or did you just setup your equation without sketching a free-body-diagram, which is required of you in question 4.6.1?

80. PT9: *No, no, no, [sic] we sketched our diagram first before setting-up our equation.*

81. **Prodding:** Your equation says ($F_{net} = \sum F = F_A = f_f + T_f$), are you saying

$F_A = f_f + T_f$, in other words, $F_{net} = F_A$?

82. PT3: *They should be equal.*

83. PT37: *Yeah, they should be equal.*

84. **Prodding:** Why should they be equal?

85. PT23: *The F_A is the one moving the two blocks, so f_f and T_f must be equal to the pulling force (F_A) if you think about it.*

86. PT17: *...because applied force (F_A) is responsible for the movement of the two blocks.*

87. **Prodding:** But, if the pulling force is equal to the forces acting in the opposite direction, do you think the blocks will still be moving?

88. PT9: *Yeah, that's what we've been saying.*

Response from Group B countering argument:

89. PT35: *I disagree with PT23 saying the F_A force should be equal to opposing forces.*

90. **Prodding:** Why do you disagree, your reason being...?

91. PT35: *Sir, if I'm to pull you towards me, and I put a force of 200N and you produce the same force (200N), we probably will remain in our respective positions. So $F_A > \sum F$ (in opposite direction) since they are moving towards it.*

Group H responded to countered argument:

92. PT17: *We didn't think of the problem like that, but, you're making sense, so F_A must be bigger then, since the blocks are moving towards its direction, is that what you're saying?*

Response from Group B countering argument:

93. PT35: *Yes, I think so.*
94. **Prodding:** So, do we (referring to group D) now agree that F_A is not equal to the sum of opposing forces ($F_A \neq \sum F_{opp. direction}$).
95. PT3, PT6, PT23, PT17 and PT37: *Yeah!*
96. **Prodding:** Next, in the equation your group constructed, you suppressed $F_{g//}$ (or failed to include it) or that you have decided to ignore its impact in the movement of the blocks. Why have you chosen to ignore or omit the existence of $F_{g//}$?
97. PT9: *We didn't think of its existence, because we had constructed our free-body diagram by following the example of yesterday's problem.*
98. **Prodding:** But, the problem we did yesterday was different, there was no inclination or angle involved compare to the present problem.
99. PT9: *We thought it doesn't matter.*

4.16 Interpretative Commentary

In constructing an interpretative summary of this session, firstly, I wanted to know whether arguments provided by the pre-service teachers consisted of any reasons to justify claims. Secondly, I wanted to know whether arguments consist of rebuttal. This is because arguments with rebuttals are said to contain an essential element of better quality arguments and to demonstrate a higher level of capability with argumentation (Erduran et al., 2004). To achieve this the session engages pre-service teachers in dialogical conversation DAIM, where they may not only substantiate their claims but also refute other claims with evidence.

Lines 78 to 88 contain the main issue of this session. For instance, group H thinks applied force (F_A) should be equal to the net force or resultant force (F_{net}), which they also assumed is equal to the sum of all the forces in opposite directions. In terms of levels of argumentation, the pre-service teachers were now operating at DAM level 3 where they begin to offer evidence to support their claim. They had previously suppressed the force of gravity parallel to the incline $F_{g//}$, and had written the (incorrect) equation ($F_{net} = \sum f = F_A = f_f + T_f$) on a poster for group

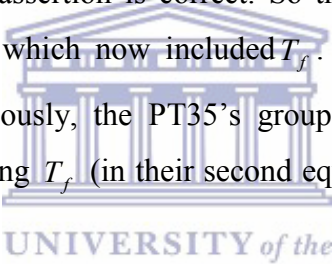
presentation {CAT stage 2}. This meant that although the pre-service teachers were becoming used to constructing and evaluating arguments pertaining to given math-in-physics problems, some of the mechanics concepts were not conceptually understood. Anomalies still exist in the knowledge they constructed. This finding corroborates one of the findings of Ndlovu and Brijlall (2016).

Rebuttal ensued when PT35 from group B countered that F_A should not be equal to the sum of forces in the opposite direction ($F_A \neq \sum F_{opp. direction}$) since the two blocks were moving towards the applied force (F_A) [DAM level +5]. In the same line of thought, PT35 provides a justification for his claim in “lines 89, 91 and 93” when he challenges PT23’s claim (“line 85”) [DAM levels 3 and +7] and {CAT stage +1}. Lines 92-95 of arguments seemed to have promoted a cognitive shift (or conceptual exchange as put simply by Hewson, 1999). Also, these lines 92-95 have branded a dissatisfaction to group H’s existing conception thereby resulting in conceptual fruitfulness or at best, what Ogunniyi (2007) calls assimilation {CAT stage 3}. The mathematical definition of F_{net} , is that $F_{net} = \sum F$. A correct representation of the net force that would lead to a correct math-in-physics solution to the problem at hand is: $F_{net} = \sum F = F_A + f_f + Fg_{//} + T_f$.

Despite some embedded complexity, as an example of arguing (lines 78 – 99), I contend that it is essentially weak as there is no attempt at a rebuttal by other groups permitting the justification of PT35 while countering PT23 [DAM level +1 & +5]. Even though PT35 argued that $F_A \neq \sum F_{opp. direction}$, he failed (during his group’s presentation) to construct a correct mathematical equation of the net force (F_{net}), in that he led the presentation that omitted T_f in the net force equation presented earlier. This is an example of types of problem-solving errors such as conceptual errors pointed out by Hodes and Nolting (1998). In this regard, the authors explain that conceptual errors are mistakes made when the student does not understand the properties or principles covered in the subject matter/textbook or lecture. But, Reif and Allen (1992) suggest that pre-service teacher’s (PT35) difficulties to set up a correct equation may not be due to erratic performances or lack of available knowledge, but due to his deficiencies in interpreting the knowledge he has.

Other groups saw nothing wrong with group H's F_{net} equation until the group was asked for math-in-physics computation using their constructed equation to find tension force [DAM level +1]. In the language of formal argumentation theory, PT35 knew and provided justification that $F_A \neq \sum F_{opp. direction}$, knowing just that this was not enough as the negation of T_f led to incorrect computations of item 4.6. An unspoken warrant exists that connects his data to his claim: the particular mathematics being used should align with the physical systems under study. The goodness-of-fit between the math at hand and the physical system attests to the validity of one's conclusions.

Group H's net force equation seems to say " $F_{net} = F_A + f_f + Fg_{//}$ " with the omission of T_f {CAT stage 2}. Their argument was that there are two parts to the equation given that there are two blocks [DAM level 3]. Such assertion is correct. So they based their justification on the provision of the second equation which now included T_f . As their two equations warranted solving for acceleration simultaneously, the PT35's group invented their own mathematical algorithms that saw them abandoning T_f (in their second equation) as a way of getting rid of it {CAT stage 2}.



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| |
|---|
| $F_{net} = F_A + f_f + Fg_{//} \dots\dots\dots(1)$ $F_{net} = F_A + f_f + Fg_{//} + T_f \dots\dots\dots(2)$ |
|---|

Some studies have de-emphasized the use of mathematics completely and focused only on students' qualitative analysis, both in instructional interventions (for example, Mualem & Eylon, 2010), and in finding predictors of problem-solving expertise (for example, Shin et al., 2003). Much more remains to be done in the analysis of pre-service teachers' ability to use dialogical argumentation as strategies to solve mathematical problems in physics. Here, I do not dispute the instructional value of prior research on problem-solving procedures that emphasize conceptual reasoning at the start and the end of problem solving. However, I see the need to consider the importance of focusing on how students process equations in their qualitative and quantitative problem solving.

For example, Group H's warrant thus suggests that they are framing their activity in terms of a math-in-physics connection. Their sketched free-body diagram derived from the two equations (1 and 2) and supports the characterization. The use of a free-body diagram as an intermediary between the physical situation and the mathematics is a commonly observed indicator of math-in-physics framing. Not only has Group H a different answer to Group D who solved the problem correctly, but they also framed their use of mathematics in an incorrect algorithm way. Another individual performance that deserves attention is pre-service teacher PT22.

4.17 Transformation in qualitative thinking exhibited by PT22 during problem-solving of item 6.3.1.

The level of qualitative thinking attained by pre-service teacher (PT22) while solving item 6.3.1 is what Piaget calls formal operations (the highest level of thinking). At observation O2, PT22 was no longer restricted to reasoning based on the here and now or on concrete evidence as she had done at observation-O1, but is capable of going beyond concrete evidence as she uses her imagination.

According to Piaget (1971), because PT22 has attained formal operations she is able to concentrate her thought on things that have no existence except in her own mind {CAT stage 4}. As a result of such thinking, she arrived at a conclusion that has hardly any bearing on concrete experience, yet is scientifically sound. Piaget explains that when a person has attained formal operations s/he can perform a variety of tasks involving the use of hypothesis, trial and error, prediction, the definition of terms, abstractions and the drawing of logical and scientific conclusion.

At the risk of being repetitive, the point is so important that it must be made again, the attainment of formal operation by PT22 not only helped her to evaluate logical possibilities, but also engaged her in creating models of heuristics in addition to those immediately available within her mind. Such levels of disposition of mental capacity demonstrated by PT22 are what I have ascribed as attainment to cognitive development. Since cognitive development is a person's mental capacity to engage in thinking, reasoning, interpreting, understanding, knowledge acquisition, remembering, organizing information, analysis and problem solving (Krathwohl, 2002).

It is worth mentioning that a suitable learning environment is essential for attaining formal operations. If students are not afforded such an environment either they take longer to get to this stage, or never do so. The next individual performance worthy of mention is PT13.

4.18 Unresolved anomalies encountered by pre-service teacher PT13 while using the nature of arguments as a strategy to solve mathematical problems in physics

This session accounted for individual performances. Pre-service teacher PT13 has had what I could describe as successful conceptual exchange or fruitfulness in most of the sessions in which arguments took place (for instance the one concerning when an object is hard to push, that it is because it is heavy). Pre-service teachers PT13, PT18 and PT2 among others have had trains of reasoning during most arguments. But this joy was short-lived. It lasted until they reached the items where they were asked to use the nature of arguments they had developed to solve mathematical problems in physics. This stage translated into a mixture of joy and sadness for most pre-service teachers, especially for PT13.

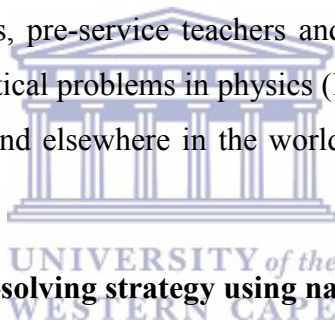
PT13 was not careful in terms of understanding precisely what variable he was dealing with and what the values associated with each variable in the antecedent equation he constructed (item 6.3.2) actually represent. The latter falls within the ambit of conceptual errors mentioned earlier similar to the case with PT35 (Hodes & Nolting, 1998). Unfortunately, with no strategic guidance PT13 was resisted by math-in-physics anomalies.

I shall return to this in the next section. Now, it is necessary to account for other pre-service teachers who managed to solve the problem in question completely and accurately, and those who struggled, more or less like PT13.

I now turn to PT 4, PT 12 and PT31. Initially when working on item 6.3.1, PT4 had arithmetic problems in dealing with variables that relate to conversion before applying them to the equation he set up. But after what looks like a sudden realization, he became good at correcting all the mistakes he had inherited by failing to deal with the mathematical error. Others, like PT12 and PT31 had no struggle computing the mathematical problems of the item.

Before turning to how the group constructed, wrote and evaluated arguments two substantive points about PT13 bear mention.. An important convenient approach PT13 could have used is that he should have first listed the symbolic meaning of each variable from the original question as far as possible before manipulating them into the formula. This would have minimized the high erroneousess he exhibited while trying to associate values given in the original question to their respective variables in the equation he initially constructed. That way it would have been unlikely to make mistakes during actual problem solving.

The second key point following from his mistakes is that he had used the wrong values for variables in the equation. He should have translated qualitative understanding of the variables in the equation into math-in-physics semiotics to enable him to analyze them quantitatively at some point. The first suggestive approach I gave would not have been necessary if the latter had been followed. In South Africa teachers, pre-service teachers and other students have had common difficulties while solving mathematical problems in physics (Basson & Kriek, 2012; Govender & Dega, 2016; Selvaratnam, 2011) and elsewhere in the world (Adler & Reed, 2002; Kuo et al., 2013; Mualem & Eylon, 2010).



4.19 Demonstration of problem-solving strategy using nature of arguments- Pre-service teacher PT39 (group A)

We know mathematics and mathematical manipulations have a regularity and reliability, and are consistent across different situations. Establishing a common underlying mathematical structure allows one to trust the relevant set of relations and inferences. It is through identifying these (relatively explicit) warrants that I was able to get information about the (relatively implicit) epistemological framing process in the pre-service teacher's mind. In order to attain clarity about how pre-service teacher (PT39) demonstrated his ability to calculate mathematical problems in physics mechanics, I have tabulated a synopsis of PT39's thought processes (see Table 4.4).

When PT39 set up the equation he constructed in item 7.6.2, he first chose direction, owing to his scientific consciousness that he was dealing with vectors. Direction is very important in understanding the vector nature of the context at hand. Next, he stated that $\sum F_y = 0$, before

proceeding to construct his equation $\sum F_y = -W + T$, but given that $\sum F_y = 0$, he then conditioned his equation as $-W + T = 0$ (the rest of his computation is depicted in Figure 4.10).

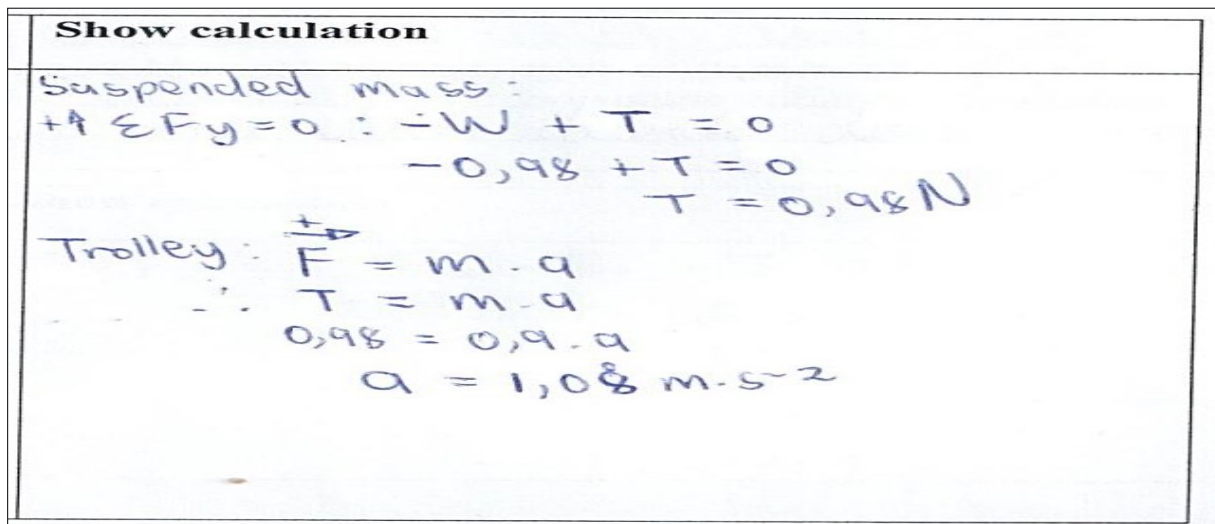


Figure 4.10 Pre-service teacher PT39's math-in-physics problem-solving

4.20 Interpretative Commentary

Implicit in this discussion is the nature of arguments used by pre-service teacher PT39. The nature of warrant is indicative of his mathematics consistency as well as other attributes he demonstrated in the process of problem-solving. In this session I looked at the dynamic cognitive process utilized by PT39. I was interested in how the pre-service teacher made an initial judgment regarding the nature of the situation at hand, and how his judgment was continually updated and reevaluated as he approached different stages in the mathematical calculations of the physics problem [DAM level +7].

In Table 4.4, it can be seen that new information comes to the pre-service teacher all the time, whether in the form of a classmate's comment, a group's interjection, the act of simply turning to a different page in a textbook, or even spontaneous random associations within his own brain {CAT stage 4}. This new information led him to reframe his activity as he recognized properties, patterns or principles pertaining to math-in-physics. He kept constructing and deconstructing his ideas with the aim of solving the problem and arriving at a correct numerical answer [DAM levels 3, 4 & 6].

As a result, the epistemological framings observed in this pre-service teacher’s work can extend over a range of time periods. I found examples in his data set ranging from ten seconds to ten minutes for the completion of the problem. It is clear that PT39 effectively used the nature of argumentation skills he was taught and that helped him to create useful strategies for solving the given problem (item 7.6.2). Studies have shown that explicit instruction in argumentation helps students to use the same practice or strategy effectively (Bell & Linn, 2000; Kuhn, 2010).

Table 4.4: Good demonstration of problem-solving strategy using nature of arguments - PT39

| Use of features of arguments | Math-in-physics connection | Recognition & Application of relevant math-in-physics rules | Mathematics consistency | Calculation-demonstration of ability |
|-------------------------------------|---|--|--|--|
| Nature of Warrant used | PT39 was able to construct suitable equation through careful observations of known and unknown variables. He then linked all concerted variables to math-in-physics | Pre-service teacher showed an understanding of properties or principles covered in the subject matter, he applied principles to situation they represent | He made logical connections to another Math idea which offers validation to physics principle or properties needed to solve the problem at stake | He correctly followed algorithmic steps that give trustworthy results |
| Other common indicators | Where applicable, he aided his Math-in-physics links with diagrams (e.g. FBD) - Created web of knowledge | Frequent quoting of rules, showing when a particular variable(s) has/have possible links. Acknowledgement of sub-structure | Shows analogy with another Math idea by making categorization | Focus on technical correctness by ensuring conceptual and procedural logics: need this to get that |

Unlike PT39, some pre-service teachers such as PT6, PT15, PT3 probably accepted their result without further thought. In PT39’s calculation framing, like all the other calculation framings that emerged from the data set, such as those of pre-service teachers PT15, PT18, PT21, etc. is primarily identified by the general nature of arguments pre-service teachers choose to use. In this case the epistemological resource or the general nature of arguments observed is the process of algorithmically following a set of established computational steps that should lead to a trustworthy result.

The specific warrants used by PT39, like all the other warrants I identified in his data set, links closely to the epistemological resources currently activated by the pre-service teacher PT39 [DAM level 6]. Epistemological resources are control structures. They lead the pre-service teacher PT39 to frame the knowledge at hand in a certain way, which focuses his attention on a particular subset of his total knowledge. As such, PT39 had to learn by imitating some of my approaches to problem solving, and so to develop an understanding of what counts as a good use of the nature of dialogical argument as a strategy for problem-solving in physics (Crawford et al., 2000). In a calculation framing, pre-service teachers like PT15 rely on computational correctness (). The warrant may be implicit, especially in non-argumentative settings.

In the section that follows I present the findings and discussion of my second research question.

4.21. RESEARCH QUESTION 2: How effective is the DAIM in enhancing pre-service science teachers' ability and sense of self-efficacy to solve selected mathematical problems in physics?

In this section I begin with an analysis of quantitative data. The qualitative data is presented later. In order to establish how effective DAIM is in enhancing pre-service teachers' ability to use the nature of arguments to solve mathematical problems in physics, I investigated two methods of teaching. These are (1) the traditional method (lecture), and (2) the Dialogical Argumentation Instructional Model method. I then computed scores obtained at various tests of the study. Scores obtained at observation (O1) represent traditional teaching (lecture method) and scores obtained at observations (O2) represent the DAIM method. In what followed, I posited a hypothesis that there is no difference between the lecture method and the DAIM method of teaching math-in-physics mechanics (2D-motions) problem-solving to the first year pre-service teachers. This was done as a two-tailed test of significance allows for the possibility that either the DAIM method or lecture method of teaching might improve pre-service teachers' ability to solve math-in-physics problems. A C-statistics was conducted to determine the possible effect of DAIM on the pre-service teachers at observations O1-O4. The findings are depicted in Table 4.5.

Table 4.5 How did pre-service teachers perform at different observations (O1 – O4)

| Group <i>N</i> = 40 | Mean Scores | C-statistics | Std. Error | 2- tailed <i>z</i> -test | |
|------------------------|-------------|--------------|------------|--------------------------|---------------------|
| | | | | <i>Z</i> - value | <i>Z</i> - critical |
| Observation O1 | 33.89 | -0.2436 | 0.1541585 | -1.5804 | 1.96 |
| Observation O2 | 46.05 | 0.2325 | 0.154159 | 1.5082 | 1.96 |
| Observation O3 | 38.95 | 0.06276 | 0.1541585 | 0.4072 | 1.96 |
| Observation O4 | 54.25 | -0.07514 | 0.1541583 | -0.4874 | 1.96 |

Level of confidence ($p = .05$)

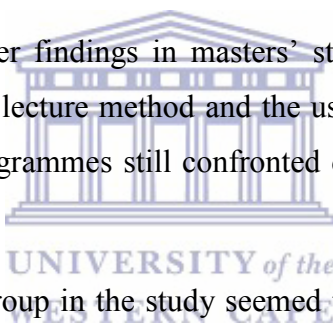
Clearly, the z-score statistic is helpful in highlighting how the pre-service teachers performed at each observation. From Table 4.5 of the 2-tailed hypothesis test, the calculated z-scores at observations O1-O 4 were much smaller than the critical z-score of 1.96 at the $p = .05$ significant level. From this consideration the null hypothesis was rejected. It was therefore concluded that there was no significant difference between observed O1-O4 performances. The reason for this is that since the observed difference between the observations as represented by z is smaller than the critical z-value, I had best assume it has risen merely by chance. It would also establish how well pre-service teachers performed relative to the mean score. In this regard, a gain score for all the observations was computed using SPSS. The graph depicted in Figure 4.11 indicates that a comparison of means is appropriate. The means score of the DAIM method (mean of observations O2 & O4 scores obtained through DAIM) is 46.05 and 54.25 compared to the means scores of 33.89 and 38.95 for the lecture method (means obtained through observations O1 & O3).

In deepening the analysis a calculation of effect size (ES) was sought. Effect size (ES) takes into account the size of the difference between means that is obtained, regardless of whether it is statistically significant. Researchers consider that any size of .50 or larger (that is, half a standard deviation Sd of the comparison group's scores), is an important finding (Fraenkel & Wallen, 2009). As regards the former, the effect size results in an ES of .20, are somewhat below .50 that most researchers recommend for significance (Robinson & Levin, 1997; Wilkinson, 1999).

4.22 Gain Scores on math-in-physics problems: DAIM versus Lecture methods of teaching

Inspection of Figure 4.11 suggests that the difference between the means of the observations scores of O1 and O3 compared to that of observations O2 and O4 should not be discounted. Thus, Figure 4.11 shows that the number of pre-service teachers gaining 5 or more points in the DAIM method of teaching is greater than in the lecture method. A gain of 5 points on a 12-item test can be considered substantial, even more so when it is recalled that if the range was 35 points on the observation O1. If a gain of 6 points is used, the numbers are 12 in the DAIM method scores (observation O2), and 7 in the lecture method. If a gain of 4 points is used, the numbers become 24 and 10. On the basis of this I argue that these discrepancies are large enough, in context, to recommend the DAIM method over the lecture method of teaching math-in-physics mechanics (motions in 2D) problem-solving to the first year pre-service teachers.

Contrary to this finding, the earlier findings in masters' studies revealed that the pre-service teachers exposed to the traditional lecture method and the use of mathematics in physics model (Redish, 2005) as intervention programmes still confronted difficulties in solving mathematical problems in physics:



- Nearly 57% of the focus group in the study seemed to subscribe to algebraic formalism with little or no qualitative understanding of the concept in question.
- They could not provide or use justifiable argument in their reasoning while solving given mathematical problems in physics.
- Most of the problem-solutions they provided showed how they were being trapped with so many anomalies, unable to proceed to interpret, analyze or solve given problems correctly.
- Many of the pre-service teachers provided solutions that contain invalid mathematical operations contrary to the algorithms steps taught.

The recent finding therefore informs the curriculum policy of the teacher training programme at the institution. It confirms that the above concerns revealed in the findings of my Masters' study about physics II and III pre-service teachers' performance in physics may have been related to the instructional method used, and not necessarily to the pre-service teachers' deficits in secondary school mathematics concepts required to solve physics problems.

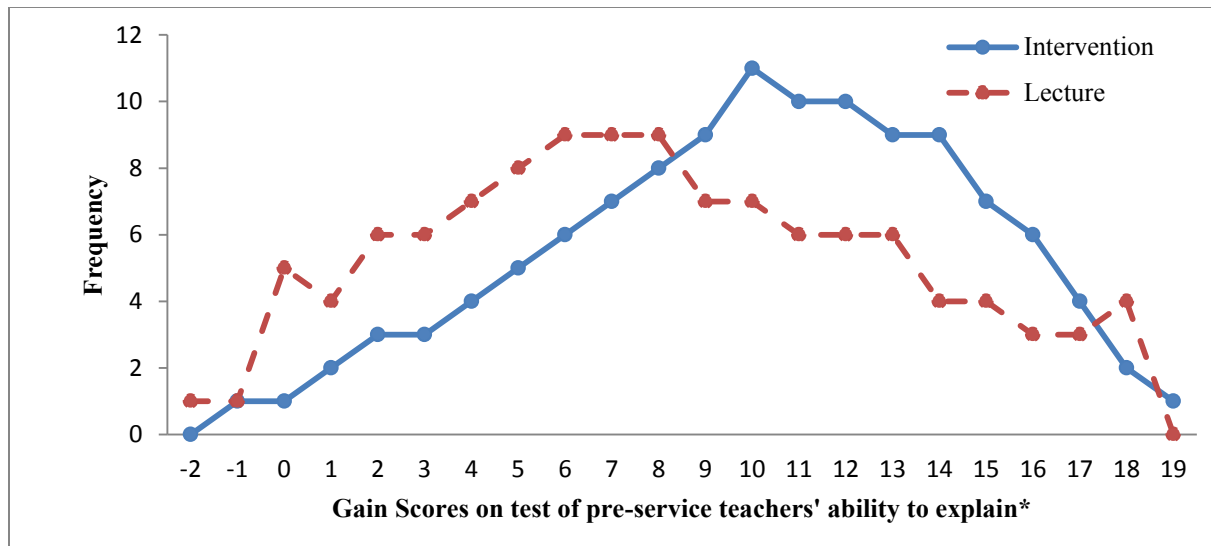


Figure 4.11: Frequency polygon showing gain scores on test of pre-service teachers' ability to explain based on DAIM and Lecture methods

[Key: A negative score indicates the observation O1 was higher than the observation O2*]

4.23 Effectiveness of DAIM: Pre-service teachers responses

In deriving data for this session, I used ten items of the instrument (Appendix F1) to investigate how the pre-service teachers' experiences in the DAIM-based lectures improved their ability to solve mathematical problems in physics. The pre-service teachers were asked the question:

“How have your experiences in the DAIM-based lectures improved your ability to use arguments to solve mathematical problems in mechanics, like Motions in 2D?” This question sought their reasons or clarification to gain further insight into the impact of DAIM on the pre-service teachers.

The ten episodes (Appendix F1) were rated in terms of the Likert scale from: (1) strongly disagree; (2) somewhat disagree; (3) neither agree nor disagree; (4) somewhat agree; and (5) strongly agree. The findings are as shown in Figure 4.12.

4.23.1 Diverging Stacked Bar Charts

Figure 4.12 shows a diverging stacked bar chart. The percentages by frequency of pre-service teachers' responses who 'strongly agree' with each of the ten items are shown in 'orange'; those who 'somewhat agree' are shown in 'light green.'

Both 'strongly' and 'somewhat agree' categories are shown to the right of the zero line. The percentages who 'strongly disagree' are shown in 'red' to the left with those who 'somewhat disagree' in teal colour. The percentages of pre-service teachers who 'neither agree nor disagree' are split down the middle and are shown in a 'very-green- light color.' The very-green-light category is omitted when the scale has an even number of choices.

A study done by Robbins and Heiberger (2011) explains that it is difficult to compare lengths without a common baseline. In this instance, I am primarily interested in the total percent to the right or left of the zero line; the breakdown into 'strongly' or 'not' is of less interest so that the primary comparisons do have a common baseline of zero (Figure 4.12). The resultant key question of the diverging stacked bar charts asked the pre-service teachers: How have your experiences in the DAIM-based teaching improved your ability to use the nature of arguments to solve mathematical problems in physics mechanics (for example, Motions in 2D)?

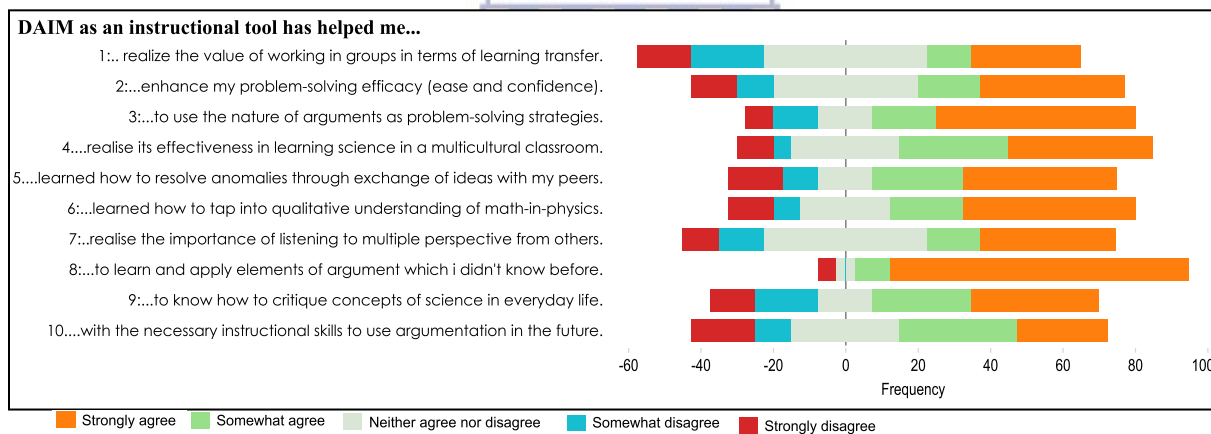


Figure 4.12 Diverging Stacked bar charts depicting the pre-service teachers’ encounter with DAIM

In keeping with the analytical approach for inferential techniques, I posited the following null hypothesis for testing:

The intervention programme (DAIM) is not effective in helping pre-service teachers improve their ability to solve mathematical problems in physics.

A popular approach was to analyze pre-service teachers’ responses using ANOVA, but on reflection of the qualitative nature of the data I proceeded to perform a non-parametric approach such as the test of Kruskal Wallis and Mann Whitney. No significant difference was found given

that the Kruskal Wallis value obtained $\chi^2 = -4.023$ ($df = 4$), given that this value is smaller than the t-critical value of 5.99. This led to the rejection of the null hypothesis (H_0) at $p > .05$.

To this end, I am equally aware that the Likert scales are subject to distortion from several causes. For example, pre-service teachers may avoid using extreme response categories (central tendency bias); agree with statements as presented (acquiescence bias); or try to portray themselves or their groups in a more favorable light (social desirability bias). One way to obviate the problem of acquiescence bias is by designing a scale with balanced keying (an equal number of positive and negative statements), since acquiescence on positively keyed items will balance acquiescence on negatively keyed items (defect to my instrument). But central tendency and social desirability are somewhat more problematic (Robbins & Heiberger, 2011). I think the acquiescence bias is probably absent in the pre-service teachers' responses (see Figure 4.12).

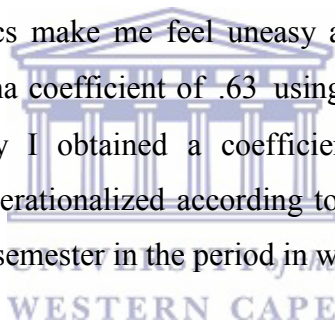
4.24 Second part of the Research Question 2: Self-efficacy

In this session, the primary aim was to determine the degree to which each of the four sources of self-efficacy in the DAIM setting: enactive mastery, vicarious experience, verbal persuasion, and physiological arousal makes an independent contribution to the pre-service teachers' self-efficacy. To accomplish this I relied on my four sub-scales measuring the effects of enactive mastery (eight items: "I got a good grade in physics class last term"); vicarious experiences (six items: "Most of the pre-service teachers I most admire are good in physics"); social persuasions (six items: "Both my High School teachers and my science lecturers believe I can do well in difficult science courses"); and physiological states (five items: "physics makes me feel uncomfortable and nervous").

For the analysis, I considered the design of the study, adequacy of the sample size, and appropriateness of techniques used. All analyses were conducted using the Statistical package for the social sciences, latest version 23 (SPSS Inc., 2015). Items on each scale were loaded onto one factor. As such, loadings for the enactive mastery items ranged from .65 to .78; for the vicarious experience from .52 to .75; for the social persuasions from .62 to .80; and for the physiological items from .67 to .76. Cronbach's alpha reliability indices were .85 for mastery; for vicarious; .87 for social persuasions; and .90 for physiological states.

Researchers, Britner and Pajares (2001) have reported alpha coefficients of .86 for science self-efficacy. In line with Bandura's (1997) assessment procedures and consistent with academic self-efficacy, a range from .69 to .85 is said to be reasonable. In this study, I obtained .78. Another area of interest in this section is the pre-service teachers' math-in-physics problem solving anxiety. These are feelings of tension and stress that interfere with the construction of math-in-physics knowledge, the development of math-in-physics skills and abilities and the use of mathematics and physics knowledge, skills and abilities in life and in academic situations (Britner & Pajares, 2001; Mallow, 1981).

The items used to collect data asked pre-service teachers to consider statements about comfort or anxiety with mathematical problems in physics mechanics (2D-motions), and to indicate the degree to which these statements reflected their feelings about physics. For instance, "Mathematical problems in physics make me feel uneasy and confused". Britner and Pajares (2001) obtained a Cronbach's alpha coefficient of .63 using a scale adapted for middle school science. Similarly, for this study I obtained a coefficient of .84. The Physical Science Achievement Test (PSAT) was operationalized according to pre-service teachers' grades in the physics class at the beginning of a semester in the period in which this study was conducted.



4.24.1 Presentation of results

Results in Table 4.6 provide Means, standard deviations, standardized regression coefficients, structure coefficients, and percentage of the explained variance consistent with the tenets of self-efficacy. Each of the hypothesized sources of self-efficacy significantly correlated with math-in-physics self-efficacy, with each other, and with pre-service teachers' scores obtained in PSAT.

Table 4.6: Indicators for the prediction of pre-service teachers' self-efficacy

| | Full Sample (N = 40) | | By Gender | | | | | |
|----------------------|----------------------|-----|-----------------------------|------|----------------|-------------------------------|----------------|-----|
| | | | Male Pre – service Teachers | | | Female Pre – service Teachers | | |
| | M | SD | β (SC) | U | β (SC) | U | β (SC) | U |
| Enactive mastery | 5.2 | 1.4 | .482*** (.854) | 28% | .456*** (.967) | 36% | .409*** (.921) | 21% |
| Vicarious experience | 3.5 | 1.2 | ns(.50) [.62*] | 0% | ns(.598) | 1% | ns(.553) | 2% |
| Social persuasion | 4.0 | 1.1 | ns(.69) [.74*] | 0% | ns(.64) | 3% | ns(.67) | 4% |
| Physiological states | 3.2 | 1.0 | ns(-.752)[- .62*] | 0% | ns(-.727) | 1% | ns(-.750) | 7% |
| Self-efficacy | 6.0 | 1.6 | .490*** (.93) | 40% | .543*** (.90) | 56% | .481*** (.91) | 43% |
| Anxiety | 2.6 | 0.9 | ns(-.456) [-.57*] | 0.9% | ns(-.547) | 2% | ns(-.359) | 3% |
| R^2 | | | .29*** | | .30*** | | .32*** | |

Note: Means (M), Standard deviations (SD), and correlations are in [] for all variables with exception of PSAT, Structure coefficients (SC) are in parentheses following beta coefficients. *U* represents the percentage of the explained variance (R^2) in the dependent variable associated uniquely with the independent variable. * $p < .05$, ** $p < .001$, *** $p < .0001$.

4.25 Interpretative Commentary

Some studies that deserve mention have shown that problems arise when the correlations, although supportive, are not very strong (Locke et al., 1984; Stumpf et al., 1987; Taylor et al., 1984; Wood & Locke, 1987). In this regard, there are four interpretations that can be used to give or generate meaning to a *moderate* or *low correlation* obtained from self-efficacy measurement.

These are as follows:

- (1) Self-efficacy is not strongly related to performance on this particular task (for example, a task in which luck plays a large part, such as gambling).
- (2) The measure of self-efficacy was not very good (i.e., weak differentiation of performance levels).
- (3) There was difficulty in assessing self-efficacy accurately (e.g., a task that was new to the subject). Or
- (4) the theory is wrong (Gist & Mitchell, 1992).

Of all the sources of self-efficacy presented in Table 4.6, only enactive mastery significantly predicted pre-service teachers' math-in-physics self-efficacy: $\beta = .482$ for the full sample (N = 40); for male pre-service teachers $\beta = .456$; and for female pre-service teachers $\beta = .403$.

Structure coefficients and uniqueness indicators confirmed these results, with enactive mastery contributing the largest percentage of the unique variance in each case: 28% for the full sample (N = 40); 36% showed male pre-service teachers have stronger mastery experience than female pre-service teachers 21%). The other three sources made only minor contributions.

Math-in-physics self-efficacy was the most consistent predictor of pre-service teachers' physics grade. Also in Table 4.6, female pre-service teachers reported higher levels of math-in-physics problems anxiety (3% versus male's at 2%). This was similar in physiological states (females at 7% and males at 1%). The present findings also support Bandura's (1997) hypothesized sources of self-efficacy, and extend previous research findings into the domain of science (Britner & Pajares, 2001; Pajares et al., 1999). Given the analyses, enactive mastery positively predicted pre-service teachers' math-in-physics self-efficacy, with uniqueness indicators. Mastery experiences accounted for a degree of variance between male pre-service teachers and females.

4.26 Self-efficacy: Individual-group attributes & performances

Studies have shown that changes have occurred in the representation of math-in-physics problems and that for skilled and less skilled problem solvers these changes are qualitatively different while a problem is being solved (Adler & Reed, 2002; Taplin, 1995; Jewett, 2008; Kim & Pak, 2002; Redish, 1999). In approaching item 6.2.3, pre-service teacher PT12 established a well thought through heuristics as a solving strategy after being exposed to a small group discussion in a DAIM setting. This entails:

1. an initial representation which was concrete or abstract;
2. a qualitative representation which provides an outline of the solution procedure; and 3) a math-in-physics representation which corresponds to the written solution to the problem.

Following the setup of his representation, his written solution differed from those he worked with in their small group. First, he converted his initial representation into one containing abstract entities from math-in-physics which enables a qualitative solution procedure to be constructed {CAT stage 4}.

Having generated a qualitative representation of the problem, which is a key element in effective problem solving, he continued by outlining components of math-in-physics from the problem statement. Put simply, he used the qualitative procedure to set up the math-in-physics representation by guiding the selection of appropriate formulae to achieve a quantitative procedure and numerical answer. Procedural details, not present in the qualitative procedure, are filled in at this stage [DAM level +7].

For PT12, the search process was now complete as a procedure that linked the math-in-physics components to the given information. He was able to think of a formula linking the problem statement to other data, such as a formula linking components (F_f , $F_{g//}$ and F_a) to given data in item 6.3.2, a predecessor of item 6.2.5. In this situation PT12 switched from heuristics (1 & 3) which he had established earlier as a solving strategy. The mathematical procedure does not supplant the qualitative procedure, which is still present to enable him to render any further explanation or simulation of the procedure that is required [DAM level 6].

In general this approach followed by PT12 is a high level representation containing a small number of steps to give an outline of the procedure. Details of the procedure are not present though they may be referred to while it is being constructed. PT12's application of this approach has been reported for the solving of problems in physics and mathematics, and with problem solvers ranging from primary school pupils to university students (Junkings, 2007; Sweller, 1988; McDermott, 1993). However, this approach is not the same for other members of his group.

4.27 Tertiary Science Classroom Observation

There are no limits set on the exploration of knowledge gained through observing science classrooms since knowledge gained can be applied to understanding human behaviour. Science has as its major premise and objective a critical and universal approach to knowledge. It seeks and finds the truth, irrespective of personal belief, bias or religious or cultural persuasion. Obviously, the role of science in our everyday life cannot be overemphasized.

During the classroom observation, I was concerned with the nature of arguments and reasoning exhibited by the pre-service teachers towards the construction of knowledge to solve math-in-physics problems.

4.27.1. Discussion on pre-service teachers' argumentation skills and reasoning towards construction of knowledge to solve math-in-physics problems

Two kinds of instruments (Appendices E1 and E2) were used for enacting classroom observation. Appendix E1 otherwise known as observation checklist E1, focused on the frequency of instances during an argumentation process. In collecting data on frequency of instances, I sought to know how the pre-service teachers in their small groups constructed, wrote and evaluated arguments. Here is a transcript of how the pre-service teachers in their small groups of 5 constructed, wrote and evaluated arguments that led to the solution of math-in-physics problems they produced.

Small group argumentation on Scenario 1

1. Aviwe pulls a lawnmower with a mass of 50kg across a lawn. His pulling force is 400N at an angle of 50° with the horizontal. Aviwe's father who stood by watching his son asked him: Son, don't you think pushing the lawnmower would be much easier than pulling it?

Aviwe replied: No dad, I don't think so. Aviwe made several attempts to justify why he said no, but could not convince his father.

Aviwe's father: Son, I insist that my suggestion would have been a better way to move the lawnmower across the field. I believe that pushing an object is easier than pulling it across a horizontal surface.

4.27.2 What is your view about the suggestion Aviwe's father gave in terms of your scientific understanding? (Item 1.1)

100. **Group A.** *Aviwe's father is right.* [DAM levels +1, -2] and {CAT stage -1}
101. **Group B.** *By pushing, you may cause damage to the machine, so pulling is a safe way to protect the machine.* [DAM levels +1 & -2] and {CAT stage -1}
102. **Group C.** *Pulling...because when you pull something it means you are going in opposite direction* [DAM levels +1 & +2] and {CAT stage -1}
103. **Group D.** *We disagree with group A, pulling...reason being that you need more force to push than to pull.* [DAM levels +1 & +2] and {CAT stage +1}
104. **Group E.** *Pulling is easier than pushing.* [DAM levels +1 & +2]

105. **Group F.** *Aviwe is right, because when you push something, the upward force add to the weight of what you're pushing, whilst if you are pulling, the upward force is directly up.* [DAM levels +1, +2, 3, 4 & 6] and {CAT stage +1}
106. **Group G.** *Pulling the lawn mower is much easier than pushing it.* [DAM levels +1 & +2] and AT stage +1}
107. **Group H.** *We think pushing is easier than pulling, less energy use.* [DAM levels +1 & - 2] and CAT stage - 1}

4.27.3 *One of your classmates may disagree with you. What might their alternative be?*

(Item 1.2)

108. **Group A.** *We disagree with group D, for example, you can't say pushing a car isn't easy than pulling it.* [DAM levels +1, - 2, 3 & -5] and {CAT stages - 1 & 2}
109. **Group B.** *We are only concerned about damaging the machine, but not the energy involved in pushing or force as H and F groups presented.* [Levels +1, - 2, 3 & -5] and {CAT stage - 1}
110. **Group C.** *We disagree with group B, Aviwe's father was not concerned about breaking the machine, but energy or work that his son must do to pull it.* [DAM levels +1, +2 & 3] and {CAT stage +1}
111. **Group D.** *They (groups A and H) think pushing is easier than pulling simply because we see people around us pushing things all the time than pulling it.* [DAM levels +1, +2 & +5] and {CAT stages +1 & 2}
112. **Group E.** *We add to what group D just said, you know the way we think and say things sometimes has something to do with what we see, often we see pushing than pulling, to us, only trucks pull.* [DAM levels +1, + 2, 3, -5] and {CAT stages -1 & 2}
113. **Group F.** *The example group A gave is complicated, because we don't need to pull a car to start it since all the four tyres must be matching the ground if we hope to start the car by pushing, if it is not meant for starting, then pulling is much easier than pushing.* [DAM levels +1, + 2, 3, +5 & +7] and {CAT stages +1 & 3}
114. **Group G.** *Those who said pushing might think that at an angle of 50 degrees it becomes easier to push it up from lower level to higher level but it becomes more difficult because of the slope.* [DAM levels +1, + 2, 3, 4, +5, 6 & +7] and {CAT stage +1 & 3}
115. **Group H.** *Why do we push all the time, and not pulling things, so others think pulling is easier than pushing, we disagree.* [DAM levels +1, - 2, 3 & - 5] and {CAT stage -1 & 2}

4.27.4 *What would you reply to your classmate to explain your position is right?*

Explain why you would accept or discard their alternative. (Item 1.3)

116. **Group A.** *We disagree with group D, may be Aviwe's father is worried about the machine or he doesn't want his son to get hurt since by pulling you'll be coming with reverse direction.* [DAM levels 3, - 5 & - 7] and {CAT stage -1}

117. **Group B.** *We agree with C, because one goes in opposite direction when pulling an object.*
[DAM levels 3, - 5 & - 7] and {CAT stage -1}
118. **Group C.** *To us, groups D and F made some points, but Aviwe don't need to draw force diagram in order to convince the father if the father doesn't know physics laws* [DAM levels 3, +5 & +7] and {CAT stages +1, 2 &3}
119. **Group D.** *We stand by our stance, Aviwe is right; he doesn't need to prove to his father, and maybe his father is too old to understand his son's explanation.* [DAM levels +1 & -2]{CAT stage +1}
120. **Group E.** *We disagree with the other people (group B)...it has nothing to do with damaging the machine, somehow, we agree with group F.* [DAM levels 3, +5 & +7] and {CAT stages +1, 2, &3}
121. **Group F.** *But, If Aviwe draw force diagram and carefully explain it to his father, he might convince him.* [DAM levels 3, +5 & +7] and {CAT stages +1 & 4}
122. **Group G.** *Carrying an object might be easier going in the normal direction but the moment we place an object on the ground it becomes very heavy making it more difficult to push but easier to pull.*
[DAM levels 3 & - 7] and {CAT stage -1 & 2}
123. **Group H.** *...because the direction we move or walk seems like the easier one but this might not be true when a mass is ahead of us.* [DAM level -2] and {CAT stages -1}

If we know the horizontal and vertical components V_x and V_y of a vector, then we can find the magnitude and direction of the vector.

124. **Group A.** *Yes...we can find the magnitude and direction using a correct sketch.* [DAM levels +1 & + 2] and {CAT stage +1}
125. **Group B.** *Yes...by using Pythagoras theorem, we can find magnitude and direction.* [DAM levels +1, + 2 & 3] and {CAT stage +1}
126. **Group C.** *Understanding vector diagram can help us find the magnitude and direction, so yes.* [DAM levels +1 & + 2] and {CAT stage +1}
127. **Group D.** *Obvious...all we need to do is to draw vector diagram and use Pythagoras Theorem* [DAM levels +1, + 2 & 3] and {CAT stage +1}.
128. **Group E.** *Yes, magnitude represent size of the components and direction, we think is the angle between the horizontal and vertical components*[DAM levels +1, + 2 & 3] and{CAT stage +1}
129. **Group F.** *Yes...the squared root of components for vertical and horizontal will give us the resultant magnitude and direction is the theta (θ).*[DAM levels +1, + 2, 3 & 6] and{CAT stage +1}
130. **Group G.** *Our answer is yes... then one can use a free-body diagram to find magnitude.* [DAM levels +1, + 2 & 3] and{CAT stage +1}
131. **Group H.** *Yes because V_x and V_y represent the sum of vectors on the horizontal and vertical directions.* [DAM levels +1, + 2 & 3] and {CAT stage +1}

4.27.5 Interpretative Commentary

The sessions of the groups' arguments were characterized in the group format (A-H). They were re-examined for the interactions among the pre-service teachers in terms of who was opposing whom, who was elaborating on what idea or reinforcing or repeating an idea. Thus, the instances where pre-service teachers were clearly against each other were traced. Here I briefly mention the interaction analysis which holds much potential for understanding what kinds of group dynamics might facilitate better argumentation among pre-service teachers.

In the episodes of the small groups' arguments, before we deal with interactions among the pre-service teachers in terms of who was opposing whom let us convince ourselves of what should have been a correct scientific response to scenario 1. Without committing any fundamental error, we can disregard Aviwe's father's suggestion for now, and return to it once we have established a scientific idea with which we can contend. Given the scenario, *Aviwe pulls a lawnmower with a mass of 50kg across a lawn. His pulling force is 400N at an angle of 50° with the horizontal.*

Simply, the intent of the scenario is to explain why it is easier to pull the lawnmower than to push it. When Aviwe pulls the lawnmower, the vertical component of the pulling force is an upward lifting force. Such force works in the opposite direction to the weight, and the resultant vertical force is smaller than the weight. If, then, Aviwe decides to push the lawnmower, the vertical component is a pushing force in the same direction as the weight. Consequently, this increases the vertical force and so it will be more difficult to move the lawnmower. To buttress this even further, using Figures 4.13 and 4.14, I showed how pulling a lawnmower is easier than pushing it.

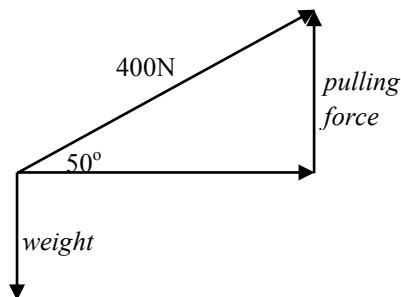


Figure 4.13 Pulling the lawnmower

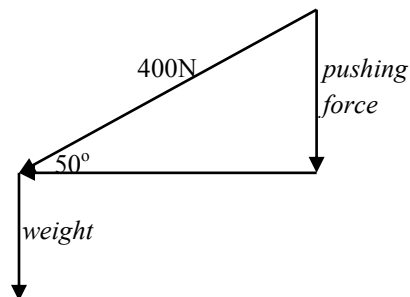


Figure 4.14 Pushing the lawnmower

The quintessential question as to whether Aviwe or his father is right is now on the menu. To filter this menu through the essence of the depicted Figures 4.13 and 4.14 as well as their earlier explanations, let us now consider the episodes of arguments produced by groups of pre-service teachers. In item 1.1, we saw that groups A, B and H had conceded that pushing the lawnmower is easier than pulling it [DAM level -7] and {CAT stages -1 & 2}. The latter can be regarded as a misconception as in the extant literature. For example, many science concepts in mechanics (like forces) have been found by teachers and researchers to be particularly difficult for students, and may well be one of the sources of the alternative conceptions they hold (e.g. Hesse & Anderson, 1992; Wandersee et al., 1994).

Contrary to the former groups (A, B and H), groups C, D, E, F, and G believed that pulling the lawnmower is easier than pushing it [DAM levels +1 & 6] and {CAT stages +1 & 3}. By means of the analytical model DAM, we can see that all pre-service teachers were willing to enter into discussion. This could be regarded as a positive attribute towards dialogic argumentation [DAM level +1]. With the exception of groups C, D, E, F, and G, the other three groups (A, B and H) offered irrelevant claims to knowledge [DAM level -2]. In accordance with correct scientific explanation {CAT stage +1}, they came very close to what Piaget calls formal operations, that is to say they attained qualitative thinking by going beyond concrete evidence as they used their imaginations to create visual information of the matter at stake [DAM levels 3, 4 & 6].

Ideally, item 1.2 sought self-regulation which expects the pre-service teachers to critically use the opponent's claim to evaluate their own stances. In place of what should have been a way to strengthen their arguments, pre-service teachers resorted to commonsensical knowledge. For example, group B was of this view: "*we are only concerned about damaging the machine, but not the energy involved in pushing or force, as H and F groups presented*" {CAT stages -1 & 2}. This kind of thinking shows fallacy in reasoning. In terms of logic, it subscribes to what is commonly known as kettle logic. Kettle logic implies using multiple, jointly inconsistent arguments to defend a position (Madsen, 2006).

Groups C-F had scientific dominance in their responses {CAT stage +1}. Exceptionally, group G tended to evaluate and judge the opponent's presumable stance(s). Even so, such an attempt is incompatible with the backing they gave in the subsequent item (1.3) [DAM stage -7].

Of course this is not surprising, since they remained stuck to item 1.4 that expected them to deliberate their knowledge about horizontal and vertical components. However, others responding to item 1.4 managed to provide satisfactory responses {CAT stage +1} and [DAM level 4]. Notably, most pre-service teachers' responses to item 1.3 are either atypical commonsensical notions or less scientifically sound. These noted challenges confirm Ogunniyi's assertion that South African learners and teachers uphold a diversity of thought systems including what he terms commonsensical and intuitive notions (Ogunniyi, 2007b).

4.27.6 Scenario 2: Group constructed, wrote and evaluated arguments

Small group argumentation on Scenario 2

Your younger twin siblings both in grade 7 were playing with spring loaded toys (a truck and a car) that can bounce off each other. Amanda picks up a truck and Jim picks up a car that is lighter than the truck. They push them against each other in the center of the living room on the wooden floor ready to let go. Before they do that, you ask: "Which one will get to reach the wall on their side faster?"

Amanda: Mine, the truck.

Jim: Mine, the car.

4.27.7 Which of your twin siblings do you agree with in terms of your scientific understanding? Amanda () Jim () State why. (Item 2.1)

132. **Group A.** *Amanda...truck can travel far distance to reach their destination than cars, cars get fault easily.* [DAM levels +1 & -2] {CAT stage -1}
133. **Group B.** *Jim...the car is smaller than truck and will get there before the truck.* [DAM levels +1 & +2] and {CAT stage +1}
134. **Group C.** *Jim...car travels faster than trucks.* [DAM levels +1 & +2] and {CAT stage -1}
135. **Group D.** *They (truck and car) will get there at the same time, if they start from the middle of the room and the walls are equidistance.* [DAM levels +1 & -2] and {CAT stage +1}
136. **Group E.** *The scenario says both the truck and the car starts from the same point of departure, so regardless of their masses, they will take the same time to get to the wall on either side.* [DAM levels +1 & -2] and {CAT stage +1}
137. **Group F.** *Not quite sure...the truck is usually slower than cars, so Jim's car will get to the wall much sooner than Amanda's truck.* [DAM levels +1 & -2] and {CAT stage -1}
138. **Group G.** *Amanda's truck is heavy, and Jim's car is light, so Jim's car will get there first.* [DAM levels +1 & -2] and {CAT stage +1}
139. **Group H.** *This is obvious, truck moves very slow than a car, Jim's car will reach faster.* [DAM levels +1 & -2] and {CAT stage -1}

4.27.8 One of your classmates may disagree with you. What might their alternative be?

(Item 2.2)

140. **Group A.** *Another group might say, but they are both toys, even so the truck is strongly built and can reach its destination first.*[DAM levels +1, - 2, 3 & -5] and {CAT stages - 1 & 2}
141. **Group B.** *There are conditions that we can consider, the scenario assumes a real life situation, and upon such context we based our stance.*[DAM levels +1, - 2 & 3] and {CAT stages - 1 & 2}
142. **Group C.** *Regardless of other people's views, a car travels faster than a truck, that's a fact.*[DAM levels +1, +2, 3 & +5] and {CAT stage +1}
143. **Group D** *Maybe others might say, since a car is lighter than the truck, it will get there faster than the truck, but there are other conditions the scenario inserted which would have been unnecessary if they don't matter.*[DAM levels +1, +2, 3, 4 & -5] and {CAT stage +1}
144. **Group E.** *If we consider, the context and conditions given, then both of them will arrive the wall at the same time, we also think since the car is lighter, others might use that to gain a point.*[DAM levels +1, + 2, 3, +5 & -7] and {CAT stage +1}
145. **Group F.** *Earlier we said we're quite unsure, this is because we defined our view from everyday life, the car and truck we see on the roads, so the car is likely to get there faster.*[DAM levels +1, + 2, 3 & 4] and {CAT stages +, 2 & 3}
146. **Group G.** *Probably somebody else might think that both cars will get there equally fast because of the springs in the car and these springs are built in a way that matches the size of the cars. .*[DAM levels +1, + 2, 3, 4 & -7] and {CAT stage +1}
147. **Group H.** *They might think a small engine of a car cannot beat the big engine of a truck, so the truck will reach there first.* [DAM levels +1, - 2, 3 & - 5] and {CAT stage +1}

4.27.9 What would you reply to your classmate to explain your position is right?

Explain why you would accept or discard their alternative. (Item 2.3)

148. **Group A.** *If we say, the car will get there first, then we need more information about the brand of the car, the materials used to make the car and truck, just because it says the car is lighter than the truck does not give it capacity to go faster than the truck.* [DAM levels 3, - 5 & +7] and {CAT stages +1, 3}
149. **Group B.** *Some cars are "sikorokoro" (that is old cars), so it may not be right to always assume the lightness of cars make them move faster than trucks. But, if all the necessary conditions are in place, cars will move faster than trucks due to mass difference.*[DAM levels 3, 4, 6 & +7] and {CAT stages +1 & 3}

150. **Group C.** *The smaller the mass an object has, the faster its speed (Newton's second law). So, we believe Jim's car will get there first before Amanda's truck. [DAM levels 3, +5, 4, 6 & +7] and {CAT stages +1 & 3}*
151. **Group D.** *Both the car and the truck are toys, they are to move from the same point, to travel to the same distance, with the car lighter than the truck, with the surface smooth, they will arrive there at the same time regardless of their mass difference. [DAM levels +1, +2, 4, 6 & +7] and {CAT stage +1 & 3}*
152. **Group E.** *If we apply Newton's third law, which says, if object A (Amanda's truck) exerts force on object B (Jim's car), Jim's car (object B) will exert equal, but opposite force on Amanda's truck (object A). This means, the masses of the truck and the car do not count, so, if mass is constant, then, force is directly proportional to acceleration (Newton's second law). So, we say the car and the truck will reach the wall at the same time. [DAM levels 3, 4, 6 & +7] and {CAT stages +1& 3}*
153. **Group F.** *The scenario says both the truck and the car are toys, so it may be wrong we translate them to everyday life, if they are to be in reality context, we still don't know the engine capacity of the truck and the car as well as other factors that need to be in place before the physics principles can be applied. This is why we said we are not quite sure. [DAM levels 3, 4 & 6] and {CAT stage 2}*
154. **Group G.** *The weight exerted on any object is very important for us to know the speed it can travel. The force acting in the opposite direction which the car is traveling can also affect it and the smaller it is the quicker it can overcome this. [DAM levels 3, 4, 6 & +7] and {CAT stage +1 & 3}*
155. **Group H.** *The bigger the mass of an object, the smaller the acceleration of the object, according to Newton's law. [DAM levels 3, 4, 6 & +7] and {CAT stage +1}*

4.28. Interpretative Commentary

A reader who is familiar with this physics problem pre-service teachers have responded to would have noted that common misconceptions exist among pre-service teachers' understanding of the context. Given their responses, let us first examine the scenario in a scientific context. The scenario asked: which one of these spring loaded toys (a truck and a car that can bounce off each other) will get to reach the wall faster if they are push against each other in the centre of the living room of a wooden floor?

In accordance with Newton's second law of motion, we seek to understand the relationship between acceleration, force and mass. In terms of the relationship between acceleration and force, acceleration is directly proportional to the force which produces it.

Thus, doubling the force will produce twice the acceleration, and so on. The mathematical relationship between the latter is written in symbols as $a \propto F$. Another factor that influences an object's acceleration is its mass. In this regard, we can say if a constant force is applied, the greater the mass of an object, the smaller its acceleration. In short, $a \propto \frac{1}{m}$. Put simply, since acceleration is inversely proportional to the mass of an object, doubling the mass of the object will halve its acceleration if the force remains constant.

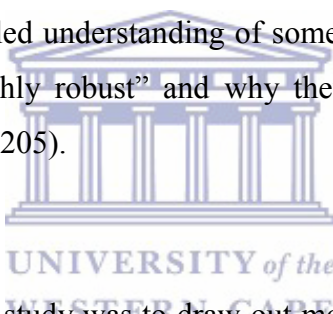
Drawing on the group responses, it was the careful thought of group E's response to item 1.3 that plausibly begged for the inclusion of Newton's third law. It is important that they made this observation. Newton's third law states that if an object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A. In the scenario both the truck and the car are hooked together so each one exerts a force on the other. In this case we cannot say which is the action force and which is the reaction force but we still call them an action-reaction pair of forces. The mathematical relationship of the latter is thus: $F_{T\text{on}C} = -F_{C\text{on}T}$, where T represents the truck, C is the car and F is the magnitude of the force.

Interestingly, this scenario has a web of knowledge situated in different unit areas of the subject matter. For instance, it places emphasis on NII, NIII laws as well as on conservation of linear momentum, that is, collision. Collision applies because when the hook holding the truck and car is released, one expects bouncing off known as collision. Group E was of the view that both the truck and the car will reach the wall at the same time. They must have assumed that since F is directly proportional to acceleration and that F on the car is the same as F on the truck, acceleration is the same. Hence the car and truck get to the wall at the same time. Here are the assertions: we cannot assume the mass of the car is the same as that of the truck.

Moreover one other condition that was never mentioned in the problem statement of the scenario is frictional force. Therefore, we cannot assume the surface the truck and car travelled is frictionless. Also from Newton's second law discussed earlier, acceleration is inversely proportional to mass. Thus the greater the mass the smaller the acceleration. In the light of these insights, groups D, E and G exhibited what Hodes and Nolting (1998) called conceptual errors.

Conceptual errors are mistakes made when the student does not understand the properties or principles covered in the subject matter/textbook or lecture.

Other groups, such as A, B and F, stressed conditions that ought to be in place in order for them to qualify/establish their stances in item 2.3.. In item 2.2 their critical look at the opponent's presumed stances seemed weak and based on commonsensical dominance. Since these were written arguments, to determine why there was little or no rebuttal would be fairly imprecise. To this end, the pre-service teachers' responses in scenario 2 revolved around alternative conceptions otherwise known as misconceptions. Misconceptions make it difficult to see what Sungur (2001) calls the "big picture," to realise the links among scientific concepts and principles, and thereby, to apply these principles meaningfully to daily life. Scientific misconceptions reported in different studies, particularly in work done by Viennot (1979) and Driver (1973), reveal a more detailed understanding of some of these misconceptions and more importantly why they are so "highly robust" and why they typically outlive teaching which contradicts them (Viennot, 1979, p.205).



4.29 Interview

The aim of using interviews in the study was to draw out more evidence concerning pre-service teachers' abilities to use the acquired knowledge in the assigned PSAT activities. The study also aims to transfer it to different math-in-physics problem contexts, say from group-to-individual and vice versa, thus increasing the reliability of the findings. To investigate follow-up effects of the intervention, eight pre-service teachers were interviewed about how they used the nature of argumentation in a DAIM environment to solve mathematical problems in physics for the first semester (6 months).

The resultant data collected through the interview instrument (Appendix G) was summarized economically on the basis of the DAIM. In specifics, this was done by means of grouping emerging themes into categories and framing these, using argumentative elements from analytical frameworks chosen for the study.

4.29.1 Interview Question 1: How have your experiences in the DAIM based-lectures improved your ability to use the nature of arguments to solve mathematical problems in physics mechanics like Motions in 2D?

Table 4.7 Categories and typical pre-service teachers' responses (Interview Q1)

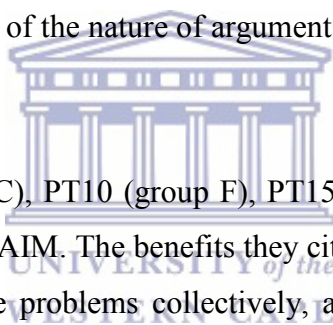
| Group | Category description | Example response |
|---------------------|---|--|
| G(A) PT21 | <u>No sure</u> . DAIM has helped me to enhance my math-in-physics problem-solving ability | <i>...I can't say it has really helped us; my group didn't experience any major change in our abilities, so most of us our marks did not improve over time. [category: Little/No impact]</i> |
| G(B) PT6 | <u>Somewhat</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>... I guess little or somehow. I'm not sure if it has made any great changes...at first, we struggled a bit in our group, but things started to improve after, I can say we noted slight improvement, but can't really say such change is a major one, maybe as time go by. [category: Somewhat]</i> |
| G(C) PT29 | <u>No doubt</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>...I would say yes, because I have learned a lot from the group method, sharing my view with others, Shane and ...eeh...yes, Adams were so helpful in our group we learned from each other. Whenever he takes the lead in the analysis of problems, he would create little tags of elements of arguments around the diagram or problem statement before we solve it. This method also helped us.[category: No doubt/some extent]</i> |
| G(D) PT15 | <u>Indeed</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>...If you notice sir, we had little or no problems solving most of the activities and answering questions posed by other groups, we were up against any challenges, so I would say DAIM has helped us a lot, even most of our course mates are getting seasoned with working in groups, we enjoy it. [category: Indeed]</i> |
| G(E) PT18 | <u>Indeed</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>...in our group, we learned from each other's relevant unit for analyzing and solving problems, this argumentation thing has taught us in our group other things, like not to talk at others while they are presenting their own views, we show respect, that's good you know...but I must say what stood out for us was the processes of arguments, we were acting like detectives, we listen, we look for weaknesses in people's views, and then we use those to make our points. [category: Indeed]</i> |
| G(F) PT10 | <u>No doubt</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>...can I ask a question first?...ok, are you going to stop this new method?...that's good, it's interesting and "lekker" (i.e. nice), now what we have learned, initially, my group wasn't so sure how to present our arguments, so we had some struggle when other groups twist our views, but later we began to make sense of the whole thing, I mean we started to enjoy it, so in no doubt we will use it in our teaching in the future, we have made some progress. [category: No doubt/some extent]</i> |
| G(G) PT5 | <u>Somewhat</u> . DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | <i>...our own story is a bit different, in the first term of the semester during the groups' presentations, we felt embarrassed as other groups were doing so well. So we started getting worried that we ain't using the...what do you call them?...whatever...oh, yes...elements of arguments correctly. So as time went by, we started catching up by watching how other groups are presenting and defending their own arguments. [category: Somewhat]</i> |

| | | |
|----------------------------|--|--|
| G(H) PT17 | To some extent, DAIM has helped me to enhance my math-in-physics problem-solving ability | <i>...I must say our group has gained new insight using this new method of teaching, ordinarily we hardly talk to each other in class, as people would sit according to the friends they associate with, (e.g. Coloured would sit with their friends, Whites on their own and we Blacks on our own), but during the argumentation sessions, we chat freely with each other, mix freely and you know we learned a lot from each other...for example, Cronje was exemplar, he's White, but we never knew he could speak IsiXhosa, Afrikaans and English until we started working in argumentation approach. Over and above, to some extent we learned from the new teaching approach. [category: No doubt/some extent]</i> |
|----------------------------|--|--|

Key: In terms of code representation G(A) = Group A and so on.

4.29.2 Interpretative Commentary

By now it is clear to the reader that forty first year pre-service teachers participated in this study. Eight groups consisting of five per group were randomly selected. A representative of each group – numbering eight pre-service teachers – were interviewed with respect to their experience of using DAIM to support their use of the nature of arguments to solve mathematical problems in physics.

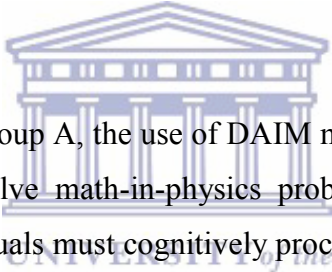


Pre-service teachers PT29 (group C), PT10 (group F), PT15 (group D) and PT18 (group E) all acknowledged the importance of DAIM. The benefits they cited lay in their small groups helping them to share their views, analyze problems collectively, and organize important information while solving mathematical problems in physics. Such behavior they saw could be developed into habits when they used argumentation in the future (PT10, group F). As can be seen from the pre-service teachers' responses, self-efficacy is concerned with the ease, fluency, confidence and facility demonstrated by an individual in performing a given task (Abbitt, 2011; Bandura, 2006). For these reasons it is evidenced in this context that the use of DAIM had influenced these pre-service teachers efficaciously in their learning of given tasks.

Pre-service teachers PT29, PT10, PT15 and PT18 from the “no doubt or indeed category,” commented on the degree to which DAIM had helped them. Another pre-service teacher said that “following the processes of arguments made them act like detectives, in that they appreciated the weaknesses in their peers' stances and used those to argue and buttress their own stances (PT18, group E). Such levels of confidence and ease in their learning after having been exposed to the new teaching method (DAIM) corroborated the judgments they made about their

competency to perform a defined task, and hence was an indication of their sense of self-efficacy (Bandura, 1982).

Pre-service teachers PT6 and PT5 of groups B and G explained that they had struggled at the inception of DAIM. Yet they claimed that over time and with the immediate feedback they received by watching other groups presenting their arguments, they started learning from them. This means that the pre-service teachers formed their self-efficacy beliefs through the vicarious experience of observing other groups perform tasks (Bandura, 2006). In other words, the pre-service teachers used the information they acquired through vicarious learning to evaluate their own likelihood of success at the same or similar tasks. Also, receiving immediate feedback has been found to raise self-efficacy (Chiaburu & Marinova, 2005). This has also been linked to the physiological arousal (anxiety, motivation and so on) to persist in an activity (Pintrich & Schunk, 1996).



As for pre-service teacher PT21, group A, the use of DAIM made no impact on their group's use of the nature of arguments to solve math-in-physics problems. Concerning this dimension, Bandura (2006) argues that individuals must cognitively process sources of self-efficacy. This is, enactive mastery, vicarious experience, verbal persuasion and physiological arousal. It includes personal and environmental factors such as previously held self-beliefs, the perceived difficulty of the task, effort expended in the task, and help received in the completion of the task. It is conceivable that PT21 (group A) might have grappled with some of Bandura's highlighted elements, hence his feelings about the use of DAIM.

Another pre-service teacher (PT17, group H) appreciated the unity the use of DAIM had brought to their learning. She goes on to say:

...ordinarily, we hardly talk to each other in class, as people would sit according to the friends they associate with, (e.g. Coloured would sit with their friends, Whites on their own and we Blacks on our own), but during the argumentation sessions, we chat freely with each other, mix freely and you know, we learned a lot from each other. For example, Cronje is White, but we never knew he could speak IsiXhosa, Afrikaans and English until we started working in argumentation approach.

Given everything pre-service teacher (PT17) stated, I believe that it is this kind of teaching approach that speaks to the heart and ideologies of Emeritus Archbishop Desmond Tutu when he advocated the rainbow nation at the dawn of South African democracy. He speaks of a cooperative and supportive learning environment, an environment of “Ubuntu” or one that conforms to the idea of "we are because you are, or your progress is my progress and progress of all". The use of DAIM in scaffolding argumentation captures the unity of many cultures and the coming-together of people of different races, in a learning environment once identified with the strict divisions of White, Coloured and Black (Source of support evidence: PT17, group H).

Pre-service teachers PT10 (group F), PT15 (group D) and PT18 (group E) were particularly excited about the use of DAIM to scaffold the use of arguments in evaluating the work of their peers during group presentation. From the accounts of these pre-service teachers’ views, one of the conveniences of exposing learners to the DAIM learning environment is that it helps to create a supportive environment. It is a 'supportive environment' like the one referred to in the investigation of the effects of cooperative group learning by Heller et al. (1992). It implies an environment where students practise a strategy (in this case DAIM) to solve problems in mixed-ability cooperative groups. It was observed by Heller and colleagues that during this joint construction of a solution, individual group members can request explanations and justifications from one another and share their knowledge as they solve a problem together. This was the case with many of the pre-service teachers’ views about DAIM.

4.29.3 Follow-up question 1.1: Do you think the DAIM has equipped you with knowledge of how to tap into a qualitative understanding of math-in-physics problems using the nature of arguments before applying algebraic manipulation?

156. Pre-service teacher (PT21 Group A): *I think a little bit, as I said before we now know we must always check to see if our reasons are correct before we start applying them, unlike before we just start solving the problems, now we are conscious, like the routine check you taught us last week, and how we can use the data in the question to check which math-in-physics principles are involved...but, this is not easy to do all the time.*
157. Pre-service teacher (PT6 Group B): *Initially, we were unable to support claims with justifications and we end up having confusions. Although we tried as time went by to use features of arguments to support our problem-solving strategies. Most members of my group couldn't recognize those elements of arguments, so we often ignore them and carry on with solving the problem. But things changed somehow; when other groups presented the problems they solved using the nature of arguments. You asked if we are equipped...I would say, somehow.*
158. Pre-service teacher (PT29 Group C): *Due to support we received from each other in our group and others, we were pretty sure what to do in most of the problems we solved, but, I must say, item 7.6.2 was somehow challenging during the first two tests we wrote and presented, but when we had to do it again, we were able to correct our mistakes, we found new ways to solve them, can you give me a paper to show you?, ok...for example...*

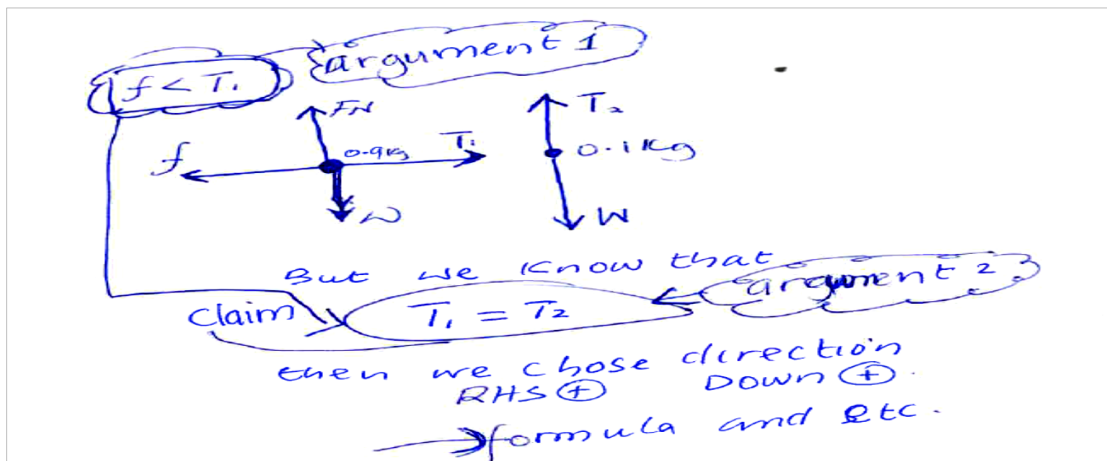


Figure 4.15: Group C's use of arguments

159. Pre-service teacher (PT15 Group D): *In our group, we didn't have many problems completing the items; this new approach has really been of great help, it's fun. So I can say it has really equipped and motivated us as first year student teachers. To many of us, we heard and learned this argumentation for the first time, not that we haven't heard about arguments, we have heard and do use arguments in our ways, but little did we know, we know nothing about the features of arguments. For example, the question you asked us in class challenged all of us...paused...yes, you asked...when is an argument not an argument? This question made us to throw away everything we used to call arguments before, because we simply talk at each other and by talking faster or more than the other talker we think we have won an argument by speaking language.*
160. **Prodding:** In one of the PSAT items (item 6.6.2), you gave un-thoughtful response when you were supposed to strengthen your argument, and now you said..."you have been fully equipped to use the nature of arguments to solve math-in-physics problems...aren't you contradicting yourselves?"
161. Responding to prodding (Pre-service teacher - PT15 Group D): *Oh no, whatever.*
162. **Prodding:** Why "whatever?"
163. Responding to prodding (Pre-service teacher- PT15 Group D): *...paused...I had said whatever, because I didn't have the right language to use at the time, so saying whatever seems to help me.*
164. **Prodding:** That's not much of a reason.
165. Responding to prodding (Pre-service teacher- PT15 Group D): *Yeah! I know it can't convince anyone, but we just use it anyway.*
166. **Prodding:** We use language to persuade, or convince one another, to sue and seek redress from, or to negotiate and arrive at understanding. Would you say you have made a point of argument by citing "whatever" to avoid further reasoning?
167. Responding to prodding (Pre-service teacher- PT15 Group D): *No special reason, I guess what I was thinking at that time was not enough that I could believe in it, so I chose a language path that we all say sometimes use when we are not sure what to say.*
168. Pre-service teacher (PT18 Group E): *First we make our observation of what is given and what is not, we would ask everyone in our group to identify important information with reasons, and then we return as a group with everyone's work on the table, we make our judgement as you taught us before solving the problem. When we get our answer, we double check, make sure everyone agrees to it before we present it to the class. This is important.*
169. **Prodding:** Why is it important to your group to double check your solutions?

170. Responding to prodding (Pre-service teacher- PT18 Group E): *If you can remember what happened the second time we presented in the first term, one of group member made a lot of mistakes, she presented out of context, we were like fools when other groups started throwing questions at us, we could not defend our arguments...I won't forget it, group C took on us. So after that presentation, we agreed that we must ensure we check every step of our work, besides we are going to become teachers, so as future teachers we need such skills.*
171. Pre-service teacher (PT10 Group F): *You noticed in all our group presentations, we sketch diagram of the problem even it is not ask. We then label the diagram with our arguments as a way to help us understand the problem, the steps, and the formula to use. We make sure we test each solution.*
172. **Prodding:** *That sounds interesting, but time consuming, don't you agree? And by the way, why do you draw diagrams even when it is not asked?*
173. Responding to prodding (Pre-service teacher- PT10 Group F): *Uhm...pause...somehow it takes time, but we task each individual to solve the problem, after that, we check to see we arrive at the same solution.*

174. **Prodding:** *And the sketching of diagram of arguments of given problem, please could you elaborate on that?*
175. Responding to prodding (Pre-service teacher- PT10 Group F): *By sketching diagram of arguments to each problem we could detect when something isn't right...what more can I say...pause...doing so helps to connect with the problem, our imaginations go places, we make connections that helps us to understand the problem better before solving it. Like now if you ask me to solve item 6.6.2, this is what we've been doing in our group. Let me sketch it...*
176. **Prodding:** *Okay, show me an example of your argument diagram of the item.*

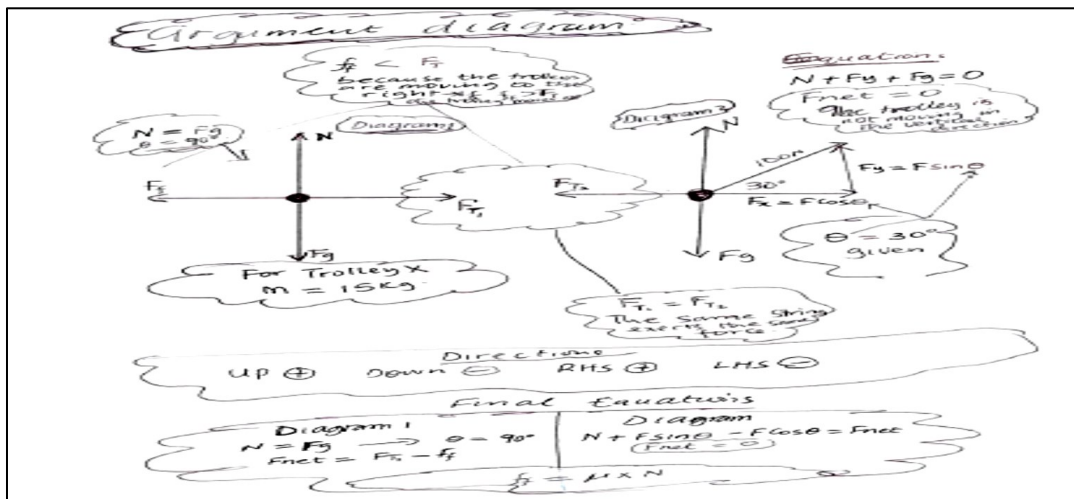


Figure 4.16 Arguments diagram drawn by PT10, group F

177. Pre-service teacher (PT5 Group G): *At the beginning, we kept solving the physics problems the way we were taught at high school, we would rely on formulae given to us by our teachers. So it became even more difficult when you introduced this new approach, now as a group we must first analyse the problem, and use the info from the question to formulate a suitable formula, and then solve the problem. As my group leader, we struggled to see reason with different interpretations from members of my group, but with time we started managing each other's interpretations.*
178. Pre-service teacher (PT17 Group H): *I don't understand the question; please explain it to me simply.*
179. **Re-phrasing question upon request:** In most cases when physics problems are given to students to solve, they would start manipulating and plugging values into formula to obtain solution without understanding the quintessence of the problem. Having worked in group underpinned by DAIM, do you think you now know how to tap into qualitative understanding of math-in-physics problems before applying algebraic formalism?
180. Pre-service teacher (PT17 Group H): *Okay I get the question! By working in group, we would give each person a chance to analyse the problem first, then each student present his/her analysis, this wasted a lot of time at the beginning, but along the line, we decided that read through the problem together, collectively we analyse it by underlining the given quantities, the unknown. We resolve arguments, different views; we choose formula and solve the problems. During analysis, a member of my group will be doing the writing, after that we set up the equation with all variables and those with calculators we compute it, we also cross-check the answer to make sure it is correct to avoid other groups attacking us.*

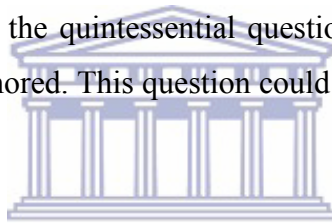
4.29.4 Interpretative Commentary

A reasonable degree of shared views about the effects of the intervention from the pre-service teachers has been documented through the interview. Some of these views captured share common categories, others do not. Different indicators or categories were used to define pre-service teachers' stances about their experiences with the use of the nature of arguments to solve mathematical problems in physics in the DAIM context.

Earlier pre-service teacher PT15 from group D explained how she uses language that has no special reason to convince or support an argument. We know when a person uses "whatever" it is either to dismiss a previous statement and express indifference or it is in affirmation of a previous statement as "whatever will be will be". Often but not always, the slang "whatever" is

used as a passive-aggressive conversational blocking tool, leaving the responder without a convincing retort. This is because much of language we hear and read (in her case “whatever”) does not contain any argument at all. It is not (as we heard from her during prodding) intended to convince us of anything, all it aims to do is to describe a situation, report an event, tell a story, or express a personal attitude. This finding on the pre-service teachers’ use of slang (“whatever”) during rebuttal extends to previous findings by Kelly et al. (1998) who report in their analysis of student language that organizing student discourse into TAP components poses language problems.

Based on the latter, we need to learn how to recognize when people (students) are using language with the intention to convince us, that is, to rely on facts we already agree about, in order to show us that we should accept other claims or assertions as well. Of course, this is not always easy to do. For PT15, the prodding raises the quintessential question why “whatever?” The legitimate sense of this question cannot be ignored. This question could be solved by prodding as we saw in the case of PT15.



In the end, she was led to view her stance as unwarranted. What has been less well understood by the case of PT15 is the context in which she constructs her argument. This is fairly imprecise. Thus, a word of caution is in order here. Even though we place a high premium on being able to supply reasons for claims, there are plenty of situations in which that demand is set aside. Alongside them, too, are other words and phrases such as "because, therefore, it follows, it's reasonable to assume, thus, my conclusion is," and so on. Some studies have shared insights on the critical role language plays in students learning. In this mode Vygotsky (1978) sees language as a vehicle of communication in the hand of the knowing adult. One of the findings by Moji and Grayson (1996), based on the effects of (English) language on African science students (English second language speakers) suggests that it limits students’ conceptual understanding of physics nomenclature, and hence introduces misconceptions.

Thus similar concerns have led to similar conclusions among pre-service teachers' use of unconvincing language to buttress their arguments. According to Toulmin, Rieke and Janik (1984), evidently reasoning or at least the giving of reasons to support claims is pervasive in our

society. This is so much the case that situations in which pre-service teachers fail to supply reasons they are expected to provide, can be lent to their pattern of analysis of the item in question.

Figure 4.15 shows how pre-service teachers transfer their manner of analyzing problems critically, for example labeling them with different argument tags before solving them (PT29, group C). One of the findings from the Voss (2006) study on “Toulmin's Model and the Solving of III-Structured Problems” says problem-solvers may frame the problem in different ways depending on their knowledge, values, and interests, and often there is little consensus on the “right” way to frame the problem.

In addition not all of them were successful in doing this (PT6, group B; and PT21, group A). For example, PT6 explains that when the argumentation session was introduced “they were unable to support claims with justifications and end up having confusions.” The challenge they faced at this stage was that they were unable to analyze and integrate the information into their written arguments. PT6 went on to say “most members of my group couldn't recognize those elements of arguments, so we often ignore them and carry on with solving the problem.” Such challenges in the experience of the pre-service teachers was not new in the extant literature, Larson et al. (2009) found that students’ ability to evaluate arguments can be improved with a little training in evaluating them and immediate feedback. This suggestion was well crafted in the methodology processes of the study; nonetheless it did not address all the pre-service teachers’ challenges.”

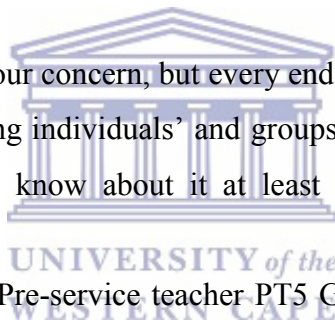
Pre-service teacher PT29 of group C said that one of the group members who led in the analysis of math-in-physics problems would create little tags of elements of arguments around the diagram of the question. Sometimes he did so on the problem statement to help identify important ideas and to understand and analyze the problem. During checking of PSAT activities completed by groups, it was found that pre-service teachers who created their tags of elements of arguments present their work thoughtfully and argue better.

In addressing the case of group E, argumentation is essential in order to define the problem and to present, justify, and evaluate solutions. According to Goldin, Ashley and Pinkus (2006), the problem solver must frame the problem, refine the goal and infer constraints. Given the response to prodding by PT18 of group E, a solution “usually is justified by verbal argument that indicates why the solution will work, and provides a rebuttal by attacking a particular constraint or barrier to the solution or by attempting to refute an anticipated opposing position” (Voss, 2006).

4.29.5 Follow-up question 1.2: What would you say are the positive and negative aspects of the use of DAIM as an instructional approach?

181. Pre-service teacher (PT21 Group A): *Working as a group, we were confronted with our individual problems.*
182. **Prodding:** Meaning?
183. Pre-service teacher (PT21 Group A): *We have our ways of doing things, to be honest with you sir, it was a bit chaotic at first... but gradually we started learning how to cooperate with each other, we shared our diverse ideas which results in a better quality of solutions. So it is positive.*
184. Pre-service teacher (PT6 Group B): *I can say working in groups slow down our process compared with us working alone. If you can remember we tend to solve the problems much quick the time we were asked to work as individual.*
185. **Prodding:** Why is that the case? What do you think is the cause?
186. Pre-service teacher (PT6 Group B): *...because we work as a group, we had to make sure every member of the group understands the problem, and clear with the arguments. So some are very slow to understand, trying to explain to them takes time.*
187. Pre-service teacher (PT29 Group C): *Most of the time we are very quick to express our own ideas such that we totally ignore what others are suggesting. The new approach sometime put us under pressure because we always want to present before others speak on the ideas we already written down, so we bound to make mistakes due to pressure.*
188. Pre-service teacher (PT15 Group D): *The new approach was quite exciting looking at the way we used arguments to solve physics problems. In addition to that we also had the opportunity to freely present our views to the class, defend our views, and correct our mistakes so I must say it is kind of positive.*
189. Pre-service teacher (PT18 Group E): *It has been a good experience for me and our group, I think the goes to other students as well. But, I am of the view that there is also something negative about it, time it takes for our group reach agreeable conclusion about any matter.*
190. **Prodding:** Can you elaborate more on this?

191. Responding to prodding (Pre-service teacher PT18 Group E): *Okay, for example, sometimes in our group, we would have no control when members of the group shifted away from the main arguments. A lot of time is being wasted when members of the group try to use everyday life explanations to support arguments; even as the group leader most times I don't know how to stop them without offending anyone.*
192. Pre-service teacher (PT10 Group F): *I had initially thought is going to be boring. I came to the realization with members of my group sharing the same thoughts that the new approach has helped us in number of ways. For instance, we solved problems with a common goal, worked together recognizing no individual differences, we argued, struggled to agree with each other's view until we are convinced the view is valid, we learned how to defend our arguments as a team. Yeah, it is positive I can say so.*
193. Pre-service teacher (PT5 Group G): *It has both sides of a coin. One of my group members tend to dominant decision-making for every concept we had to deliberate on, he barely give others a chance to say something, I believe everyone's views matters in a group activities. Besides that the approach is somehow beneficial.*
194. **Prodding:** Mr....I hear your concern, but every end of the topic unit we always meet to deliberate on issues affecting individuals' and groups' activities, why you never brought up this concern or let me know about it at least I would address the individual in question?
195. Responding to prodding (Pre-service teacher PT5 Group G): *I don't want to mention name, she is a good student though, she knows the work and because of this she tends to say "no need to waste time deliberating on this or that issue, let's solve the problem, I know what and how to do it." So this statement always make the speaker to keep quiet or at worse get upset feeling that his or her views does not matter. What I can is that we have mixed feelings.*
196. **Prodding:** Noted, Mr....
197. Pre-service teacher (PT17 Group H): *...pause awhile, uhm...I would say positive in the sense that it has made most of us to be more excited about arguments, I can remember last year (2015) when I was in grade 12, we had a science debate, it was nothing than talking at each other, those who can speak English fluently sounded cleverer than those who cannot express their views fully in English. So whether what those who can express themselves in English are saying is relevant or irrelevant, our teacher tend to rate them high and to turn blind eye to others. So from this new approach, I can even see that our high school teacher was wrong in the way she assessed us.*
198. **Prodding:** Uhm...so tell me how the new approach made you realized your present proposition.



199. Responding to prodding (Pre-service teacher –PT17 Group H): *After we were exposed to argumentation, I learned there elements of arguments, when is argument is not an argument, how to qualify an argument, we never heard of such from high school during science debate. Now I can see that many of my classmates' views during debate at high school were right if you follow the processes of arguments. It's not about one's ability to speak English fluently, but providing valid reasons to justify one's views. All these and more we have learned in this new approach.*

4.29.6 Interpretative Commentary

Group C comment seems to have negative connotations. They unconsciously perceive the situation as competitive. It is easy to think the group had embraced the new approach (DAIM) as a way of competition. This generates behaviour which drains the creative energy of the group. Such narrated behaviour from group C creates an atmosphere which is incompatible with effective problem solving.

For example, PT29 says “most of the time their group worked under pressure to avoid other groups speaking on the ideas they have written down.” Not only that such unnecessary pressure may lead to mistakes, but it will inevitably affect the quality of arguments they produce collectively as a group. Hence PT29 again says “we totally ignore what others are suggesting as we are too quick to express our own ideas.” Thus, the natural reaction is to regain self-esteem, often by trying to sabotage the ideas of those who disagreed with us. Instead of looking for ways to improve on their ideas we choose to destroy them by ignoring useful suggestions generated by others (LaBossiere, 2002, 2010). At worst, as will be seen later in the summary of findings of this chapter, such behaviour could lead to ad hominem exchanges as it is possible that the group might perceive disagreement with their own ideas as a put-down.

Apart from the negative attributes of the new approach (DAIM), positive attributes seem to cultivate cross fertilization. That is, pre-service teachers (groups A, D, E, F and G) seemed to have enjoyed the exchange of ideas while working in groups. Such orientation can act as a stimulus to the imagination, encouraging individuals to explore ideas they would not otherwise consider. With each pre-service teacher's differing experience, knowledge, points of view and values, a larger number and variety of ideas for solving a problem can be produced.

Given the train of thoughts in the foregoing section, excerpts from groups B, D and E can be summarized in the following manner. The shared responsibility of a group in arriving at decisions can encourage individuals to explore seemingly unrealistic ideas and to challenge accepted ways of doing things. On the other hand, the negative connotation we learned from group C may give us another thought if we flip the coin the other way. Thus, group pressure can also encourage individuals to accept that change is needed. Experience has led to the conviction that, on the one hand, individual biases and prejudices can be challenged by the group, forcing the individual to recognize them.

To this end, I can sum this up as follows: the intervention (DAIM) gives a common purpose to the pre-service teachers working in small groups, within which individuals can gain a feeling of self-determination and recognition through their contribution. Individuals who have contributed to finding a solution feel a greater commitment to its successful implementation (see PT6 group B, PT17 group H and PT15 group D).

4.30 Interview Question 2.1: How confident and at ease are you now with math-in-physics problem-solving compared to before the intervention programme (DAIM)? Rate yourself on a scale of confidence and ease with math-in-physics problems like Mechanics 2D motions.

The rating scale associated with question 2.1 is as follows: 1–Nothing has changed for me; 2 – I’m neither comfortable nor at ease; 3 – I am somewhat comfortable and at ease; 4 – I am comfortable and at ease; and 5 – I am very comfortable and at ease. The excerpts below are extracted from the interviews conducted with the pre-service teachers:

200. Pre-service teacher (PT21 Group A): *I am somewhat comfortable and at ease.*
201. Pre-service teacher (PT6 Group B): *I am somewhat comfortable and at ease.*
202. Pre-service teacher (PT29 Group C): *I am comfortable and at ease.*
203. Pre-service teacher (PT15 Group D): *I am very comfortable and at ease.*
204. Pre-service teacher (PT18 Group E): *I am comfortable and at ease.*
205. Pre-service teacher (PT10 Group F): *I am comfortable and at ease.*
206. Pre-service teacher (PT5 Group G): *I am comfortable and at ease.*
207. Pre-service teacher (PT17 Group H): *I am very comfortable and at ease.*

4.30.1. What is/are the reason(s) for your response? (Interview question 2.2)

208. Pre-service teacher (PT21 Group A):please ask me later. {Not ready!}

209. **Interviewer:** That's ok.

210. Pre-service teacher (PT6 Group B): ...*understanding how to analyse and solve physics problems using arguments is something new and exciting to me and members of my group. It gets even more exciting when we had to solve the problems individually and then as a group. We could see the differences. Even though I am not the best problem solver in my group, but working in group has helped me to learn.*

211. Pre-service teacher (PT29 Group C): *All I can say is that despite the issue of time wasting [sic] I mentioned earlier, my understanding of how to interact with others has improved. I completed both my primary and high school at schools where there were no Black learners, so coming to university is my first time sitting and learning under the same roof with Black students. So I enjoyed how everyone in my group worked together. Different styles of learning, so I have learned different ways to think and solve problems.*

212. **Pre-service teacher (PT21 Group A):** *In the beginning I knew what I was capable of , after my exposure to the new approach I started to reason different, I no longer jump into conclusions until I have satisfactory reasons to do so. The same goes to solving problems in physics or mathematics, I now have to do self-arguments within my mind before attempting problems.*

213. **Pre-service teacher (PT15 Group D):** *I value the new approach, having gone through it, I feel comfortable in solving physics problems using arguments. In a lot of ways, it helped me gain different perspective from my colleagues.*

214. **Pre-service teacher (PT18 Group E):** *Now I am quite passionate about the new approach, since the new approach began I have learnt to look at things differently especially in the way I solve physics problems. I am more critical now than before and can express my view much better without being offensive if or when people disagree with my views.*

215. **Pre-service teacher (PT10 Group F):** *It is through this new approach I gained more insight on how to solve physics problems, before I would just look for a formula for the variable in question and once I got it I would plug other stuff in the question and find an answer. But now, it is different, I read the problem critical and analyse it with reasons and until I see that my thoughts are reasonable I don't rush for formula as I used to do. So the whole approach is helpful.*

216. **Pre-service teacher (PT5 Group G):** *Now I am more eager to look at physics problems critically using arguments, sometimes I argue against myself during analysis, with time I'm growing more confidence to solve problems in physics and mathematics carefully.*

217. **Pre-service teacher (PT17 Group H):** *An important benefit of this new approach is that it encourages us to support one another in the group. Doing this we learn to value each other's contribution and way of solving problems. In our group it is a win-win situation everybody wins, because each time we solve problems collectively we improve in one area or the other individually.*

4.31 Interpretative commentary

First of all, effectiveness of any instructional model is often based on how well it helps students (in this case, first year pre-service teachers) to learn presented activities meaningfully by achieving the desired goals and objectives of the activities.

Findings from the interviews are consistent with other results discussed earlier in this chapter. Moreover, findings derived from the interviews conducted with the pre-service teachers have provided additional insights into the studies in the area, particularly in relation to the critical role that mathematics plays in the understanding of mechanics in physics. Most of the earlier studies seemed to focus mainly on misconceptions in physics without paying much attention to the inherent mathematical concepts in the subject.

It must be remembered that proposed activities of PSAT were not only aimed at exploring the pre-service teachers' knowledge about specific physics content but also to determine to what extent argumentation instruction such as the DAIM has enhanced their ability to teach their subject more efficaciously. However, from the evidence based on the excerpts of the interview it is fairly imprecise to infer that all pre-service teachers involved in the study have actually acquired a profound knowledge of the specific contents addressed.

Furthermore, as can be seen from their responses to the question that asked about their confidence and ease to use the nature of arguments to solve mathematical problems in physics under DAIM settings, the eight pre-service teachers representing the small groups of forty explained areas of progress, regression, their views about the intervention (DAIM) as well as

how the intervention programme helped their ability to solve mathematical problems in physics efficaciously (for example, PT6-group B; PT21-group A; PT15-group D; PT18-group E). Caution should be drawn here.

The pre-service teachers' claims about their confidence and ease with math-in-physics problem-solving and the actual results of the mathematical problems in physics they solved in all the four observations are somewhat incompatible. I acknowledge there has been some degree of improvement on the pre-service teachers' ways of thinking, reasoning, analyzing and solving problems, hence their ability since the inception of the intervention programme DAIM. But I also think to a certain extent they have exaggerated their ability to solve mathematical problems in physics. In this regard, more detailed evidence is presented in the summary of findings of this chapter.

Added to the above, it was also noted that even after the intervention, more than half of the participants (21 out of 40) have not referred to relevant scientific concepts to justify their arguments on the proposed issues. This evidence confirms previous results that students' informal reasoning about problem-solving of basic mechanics often relies on personal experience, emotive and social considerations rather than specific content knowledge (Jewett, 2008; Heller et al., 1992; Kim & Pak, 2002; Redish, 1999). It also suggests that the proposed activities need further improvements.

I now present the summary of all my findings.

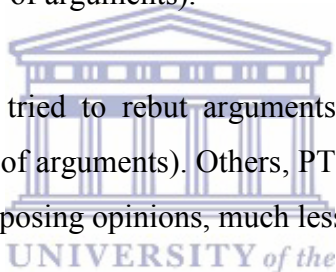
4.32 Summary of findings

It will be seen, therefore, that 'arguments produced by some pre-service teachers' have given the findings in this chapter a positive and a negative outcome. In terms of the outcome, 'emancipation of sound arguments' was noted among the pre-service teachers, in contrast to fallacies in reasoning found in many of the pre-service teachers' arguments when they solve mathematical problems in physics. What remains to be seen is the extent to which the pre-service teachers will use what they learned (dialogical argumentation) in different situations to solve

different problems as well as how they will use it in their own teaching when they join the teaching profession.

4.32.1 Findings related to pre-service teachers use of argumentation as problem-solving strategies

- At observation O1, pre-service teachers tend to accept the claims of their peers and move onward. In most discussions few pre-service teachers included grounds for their statements. And some of those who did simply agreed or disagreed by merely repeating the portion of the comment with which they agreed or disagreed.
- Few of the pre-service teachers (such as PT10, PT8, and PT22) were able to support claims with justification and some even provided alternative perspectives with justifications (see lines 6-10 of arguments).
- Some pre-service teachers tried to rebut arguments but their rebuttals were weak or inadequate (see lines 11-24 of arguments). Others, PT15, PT29 (see lines 25-31) could not recognize the grounds of opposing opinions, much less undermine them.
- Clear cognitive shift between observations (O1 and O2) were noted among the pre-service teachers, for example, at O2, eleven pre-service teachers were able to use the nature of arguments correctly, with justification and Single/Multiple grounds, with counter-claim and rebuttal. It is reasonable to regard these pre-service teachers as good problem-solvers.
- At the third observation (O3) level, few pre-service teachers (thirty-two percent) were able to provide justifiable arguments pertaining to a given problem and its possible solution. Others (about twelve percent) grappled with the conceptual resource of the given problems. Of those who tried to solve the mechanics problems a slight improvement was noted in the way they interpreted numerical answers they had obtained at one stage or the other to see whether the answer(s) make sense or not.
- At the fourth observation (O4), 14 pre-service teachers attempted 12 PSAT activities, and were able to use argumentation skills to mobilise mathematical concepts needed to solve



physics problems of mechanics by providing justifiable arguments pertaining to a given problem and its possible solution.

- In terms of correct usage of the nature of arguments during individual and group discussions, it was found that the highest percentage of pre-service teachers' discussions belongs to DAM level -2 (36.8%) as opposed to 32.3 percentages at DAM level -1. Pre-service teachers' correct scientific knowledge was dominant at CAT stage +1 (54%) and commonsensical knowledge was dominant at CAT stage -1 (46%). Notions held by pre-service teachers were suppressed at 48% CAT stage 2. There seems to be a lower percentage of discussions classified at DAM levels 3, 4 and +5 (17.5%, 11.3% and 12.5% respectively).
- Significance of rebuttal, additional rebuttals, ideas held by the pre-service teachers were assimilated at 52%, CAT stage 3. Retaining of notions stood at 48%. This effect may be attributed to the scaffolding of pre-service teachers' dialogic argumentation skills.
- It was noted that conceptual fruition or change/exchange linked to cognitive shift emanated from notions being assimilated. As observed, pre-service teachers became dissatisfied with their existing notions as rebuttal increased.
- Statistically, relations between the levels of pre-service teachers' dialogic argumentation and their performances on the use of the nature of arguments to solve mathematical problems in physics, was found at ($\chi^2 = 12.67$ $df = 3$ $p < .001$). This relation may be attributed to the tendencies that appear within tables (see Tables 4.3 and 4.4).
- By correlating pre-service teachers' problem recognition and their actual ability to solve problems, it was found that problem recognition had little effect on their ability to solve the problems. In other words, the number of pre-service teachers who said yes to problem recognition (Observation O1 = 33 and Observation O2 = 34), with only 18 of them at O1, and 21 at O2 who were able to solve the problems they claimed to have recognised (see Figure 4.3).

- Over time (observation O4) pre-service teachers had improved their ability to use the nature of arguments to solve math-in-physics mechanics problems, (2D-motions). This means more pre-service teachers had gained entrance between the categories AA, AB, and AC, predominantly the AB category, indicating that those who did so had moved from being average problem-solvers to being good problem-solvers.

4.32.2 Findings related to the effectiveness of the intervention programme (DAIM)

- Pre-service teachers' response choices relative to the effectiveness of DAIM showed that those with a higher frequency of responses agreed that the intervention enhanced their abilities to solve math-in-physics problems, compared to those with lower frequencies (see Figure 4.13).
- No significant difference was found given that the Kruskal Wallis value obtained $\chi^2 = -4.023$ ($df = 4$) is smaller than the t-critical value (5.99147); thus the null hypothesis (H_0) was rejected at alpha level $p > .05$.
- As shown in Table 4.6, only mastery experiences positively predicted pre-service teachers' math-in-physics self-efficacy. This was more evident among the male pre-service teachers than the female ones.
- Even for the most successful problem solvers in the study there seems to be a lack of basic conceptual understanding of physics concepts relating to mechanics. One common explanation is that the pre-service teachers' everyday experiences (based on commonsensical knowledge) seem to contradict physics principles.

4.32.3 Challenges faced by individual groups to use the nature of arguments in DAIM setting

- Group B was unable to support claims with justification in most PSAT activities and ended up having "confusions." The challenge they faced at this stage was that they were unable to analyze and integrate the information into their written arguments. Most members of this group could not recognize the elements of arguments that had been taught. In most cases they would ignore them and carry on with the process of solving the problem (Support evidence: Excerpts of PT6-interview).

From the excerpts of arguments, pre-service teachers' views of physics phenomena, conceptions, and explanations:

- differ markedly from current orthodoxy in physics (evidence based on work of PT11, PT29, PT1, PT6, PT10 and others)
- show similarities with past historical misconceptions in physics (evidence based on work of PT11, PT8, PT20, groups B, E and A)
- are very tenacious in the face of traditional expository teaching of physics (evidence based on work of groups A, B and H)
- serve useful purposes for them in everyday encounters with physics phenomena, and hence seem more plausible than physics orthodoxy (evidence based on work of groups C, D, E, F, and G)
- can seriously hinder their further learning in physics cognitively (evidence based on works of PT11, PT8, PT1 and others).

4.32.4 Findings related to challenges pre-service teachers grapple with to construct, write and use argument during problem-solving

- Many pre-service teachers demonstrated fallacy in reasoning. Their reasoning was either subsumed by commonsensical knowledge or scientifically invalid. For example, in one of the PSAT items tested, pre-service teachers argued that a force is necessary to keep an object moving, and that the speed of an object depends on the strength of the force as was the case with Greek philosopher, Aristotle. Several errors in calculated solutions of given problems were found.
- Errors those described by Hodes and Nolting (1998) as careless conceptual application and procedural errors were found in the work of pre-service teacher PT15 (see Figure 4.9). However, because PT15 was solution-focused, she was able to perform math-in-physics problem (item 3.6.2) even though she held an incorrect physics principle side-by-side with correct mathematical calculations. She knew the math-in-physics concept but could not apply the physics principle or property covered in the subject.

4.33 Fallacies in reasoning – Processes of arguments followed by pre-service teachers

If we are to understand what a fallacy is, we must understand what an argument is. As already explained earlier, an argument consists of one or more premises and one conclusion. A premise is a statement (a sentence that is either true or false) that is offered in support of the claim being made, which is the conclusion (which is also a sentence that is either true or false).

A fallacy in reasoning often refers to errors in reasoning, appeal, or language use that renders a conclusion invalid. A fallacy can either be formal or informal. It is a commonly used style of argument where the focus is on communication and results rather than the correctness of the logic, and may be used whether the point being advanced is correct or not (Madsen, 2006). The following findings are related to fallacies in reasons found among the pre-service teachers.

4.33.1 *Appeal to Ignorance*

In argument, an appeal to ignorance asserts that a proposition is true because it has not yet been proved false. This is a fallacy in informal logic (Madsen, 2010). Evidence of this kind of fallacy is found in lines 4, 6 and 9 of arguments, in that group A used their opponents' (groups D and F) inability to disprove a conclusion as proof of the validity of their own conclusion: “Sure, groups D and F can’t prove pulling is easier than pushing, so we must be right.”

4.33.2 *Faulty Cause*

Another fallacy in reasoning found in the excerpts of pre-service teachers’ processes of argument is what is known as faulty cause. This fallacy in reasoning (faulty cause/shifting the burden of proof) is often mistaken correlation or association for causation by assuming that because one thing follows another it was caused by the other. For example, in responding to item 4.6 of the PSAT instrument, group D provided an equation that says $F_{net} = \sum F = F_A = f_f + T_f$. The reader familiar with the physics of this item 4.6 (Appendix C) will recognize that ($F_{net} = ma$) can be translated into ($F_{net} = \sum F = F_A + f_f + Fg_{//} + T_f$) and not what the group had stated. It was found during prodding (see lines 1-11 of arguments) that group D had derived their incorrect equation through association for causation. This they did by assuming that “because applied force F_A is the force moving the two blocks, so f_f and T_f

must be equal to the pulling force (F_A).” By associating this causation, PT2 from the group added “applied force (F_A) is responsible for the movement of the two blocks.”

4.33.3 Kettle Logic

Found in the excerpts of PT 10’s argument is one potential fruit of what is known as kettle logic. Kettle logic implies using multiple, jointly inconsistent arguments to defend a position. Evidently, this was the case with PT10’s response to one of the PSAT items tested. Pre-service teacher PT10 was asked (item 3.4) to explain why he would accept or discard a view opposing his about the claim that says everything that moves will eventually come to a stop. First he stated “line 9” of arguments; then he responded in the form of association for causation. Lines 30 and 32 are evidence of inconsistent arguments:

I would discard their alternative based on the law of conservation of momentum (line 30)...why do you think this?, he was asked, he says nothing can be at rest as it is always moving relative to something else (line 32).

With this we encounter a science principle (law of conservation of momentum) whose extent has no association for causation as PT10 believes. PT10’s accidental equivocation is an example of faulty cause. By accidental equivocation, I imply that PT10 had allowed “line 30” of his argument to shift incompatible meaning with “line 4” during the course of the argument. The result is that the conclusion of the argument is not concerned with the same thing as the premise(s).

4.33.4 Quantification Fallacy

A quantification fallacy is an error in logic where the quantifiers of the premises are in contradiction to the quantifier of the conclusion. As noted, this fallacy in reasoning – quantification fallacy – was found in pre-service teacher PT15’s work as she responded to problem-solving of the 2D motion item 3.6.2. In brief, item 3.6.2 presented a context in which a wooden box weighing $100N$ is placed on a metal inclined at 30° to the horizontal. By using appropriate calculation, the item asked students to show whether the wooden box was in a state of rest. PT15 stated “if there is acceleration calculated, then we know that the box is moving.” What holds true in the context was: if the box is at rest, then the net force acting on it is zero.

Even though she did not have major difficulty performing the mathematical calculations of the physics problem, her logic was contextually incorrect.

In terms of scientific philosophy, Riehl believes Logic is an objective science as is mathematics, which is closely related to it (1907, p.74). I believe science has its concepts and its conceptual connections, and that if the logic of the conceptual connections is to be understood, then one should explain logic in the context of the sciences. Misleading explanations of logic are in fashion (in the case of PT15). What holds true in the context is evident in that the quantifier of the premise is in contradiction to the quantifier of the conclusion.

4.33.5 *Straw Man*

This is a technique where you misrepresent the views of the opponent by making their argument seem weaker or (dumber) than it is. For example, item 1 asked pre-service teachers which method is a better way to move a lawnmower across a field, pushing or pulling. Compared to other groups (G and F) we see the groundlessness of group B's response.. The redundancy of group B's stance says:

“We are only concerned about damaging the machine, but not the energy involved in pushing or force as G and F groups presented. [DAM levels +1, - 2]{CAT stage - 1}

The call of the group B's rebuttal had come from the transition of warrant provided by groups G and F respectively:

Group G...stated that pulling the lawnmower is much easier than pushing it. [DAM levels +1, +2]. Group F...pulling, because when you push something, the upward force adds to the weight of what you're pushing, whilst if you are pulling, the upward force is directly up.[DAM levels +1, +2, 3 & +7]

Taken together, whatever the general merits of group B's views amounted to, they indicate a fallacy known as straw man because they [group B] were not addressing the real issue, and have proved nothing as they were concerned about damaging the lawnmower.

4.33.6 *Appeal to Tradition*

In responding to item 5.4, pre-service teacher PT6 says:

I listened to what Soraya, Siphon (pseudonyms) and others are saying, but why do we always pull light objects and not push them? It is because the heavier the object is, the

more difficult it is to push it. Guys, I'm talking about what we do and not what science says [*sic*]. So I say objects are hard to push because of its weight. {CAT stage -1}

Here we can see that the stances (backing) provided by PT6 conform to what is known as an appeal to tradition. In what followed from his acknowledgement of peers' stances, we hear the appeal, "guys, I'm talking about what we do and not what science says." Presumably, what PT6 is saying is that since it has always been that way, it should continue to be that way. Traditions can be important, but they are not all equally rational. This type of thinking can be a fallacy. The result is that the conclusion of the argument is not concerned with the same thing as the premise(s).

4.34 Findings from interview items

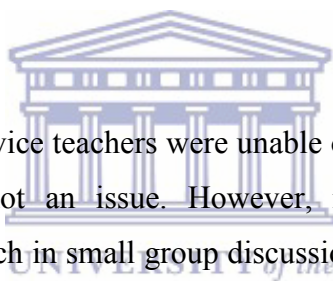
- I noted that the use of the DAIM in scaffolding argumentation captures the unity of the many cultures and the coming-together of people of different races, in a learning environment once identified with the strict divisions of White, Coloured and Black (Source of support evidence: PT17, group H).
- The use of arguments in the DAIM setting has helped the pre-service teachers transfer their behavior of analyzing problems critically, for example labeling them with different argument tags before solving them (PT29, group C). Not all pre-service teachers in their small groups were successful in doing this (PT6, group B and PT21, group A).
- In terms of math-in-physics problems solved by groups, it was found that groups who created tags for elements of arguments during their analysis of any particular problem showed good understanding of the problem, presented their work thoughtfully and argued better.

4.35 Paucity of the group use of nature of arguments

The paucity of the use of the nature of arguments by groups (A and B) could have been due to several reasons. One may be the quantity of the PSAT activity. In total there were sixty-one items comprising the PSAT instruments. These were completed unit-by-unit in each session

covered during the lecture week. A test was carried out at the end when all the units had been completed. Thus, pre-service teachers may not have been concerned about the quality of their arguments. An alternative explanation is that pre-service teachers might not have had a clear understanding about when and how to apply the elements of arguments.

From another interviewed group, it was found that despite the success story painted by the group about their experiences in using the nature of arguments, some pre-service teachers (groups C and F) could not solve PSAT items 6.6.2 and 7.6.2 correctly. A third reason might have involved the individual relationship. Because the groups were diverse by reason of race, unease might have existed as individuals tried to harmonize their working relationship. From classroom observation obtained through the video recorder, it was noted this could have had some effect. Evidently, the appreciation of the case of PT17 discussed earlier, shows that with time an improvement may be occur.



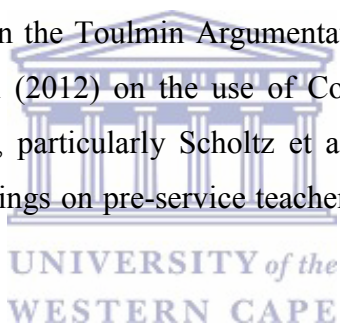
The question as to whether pre-service teachers were unable or simply unwilling to work in their respective diverse groups was not an issue. However, more importantly, the use of an argumentative instructional approach in small group discussion should benefit tasks in increasingly multicultural South African classrooms. This will in the long run help to nurture and harmonize individual differences often managed by race. Argumentation skills are therefore essential for pre-service teachers and those who are already in the teaching fraternity, to learn how to address problem-solving not only in domains like law or ethics.

4.36 Summary

It is an open question as to whether or not all the observed changes in the pre-service teachers' ability to solve math-in-physics problems have made a long and lasting impact. What remains to be seen is the extent to which they would apply their knowledge gained in a different context other than the one to which they were exposed. Owing to the smallness of the improvement in the case of pre-service teachers (PT10, PT23, PT18, PT22, PT28, PT39), it is difficult to form an opinion as to whether or not the recorded improvement is traceable among all pre-service teachers who participated in the study.

At the present time, much work is being done to analyse students' inabilities to solve basic physics mechanics problems (Kim & Pak, 2002). The same applies to students' conceptions of the use of maths in physics problems (Redish, 2005); student confusion in how to solve mechanics problems (Jewett, 2008); students' deficiencies in interpreting the numerical answer they obtained in a given problem and the knowledge they have (Reif and Allen, 1992), and students' inabilities to connect maths-in-science knowledge (Junkins, 2007).

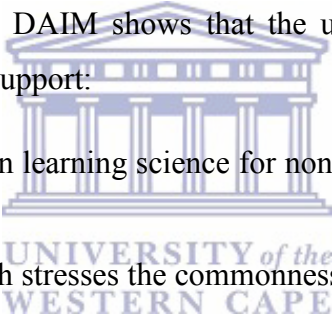
Researchers are working with great zeal towards finding long and lasting methods to ameliorate students' inabilities to solve math-in-physics (Bing & Redish, 2008, 2009; Govender, 2007; Gupta & Elby, 2011; Hestenes, 2010; Junkins, 2007; Kuo et al., 2013; Martinez-Torregrosa et al., 2006; Redish, 2005). Osborne et al. (2004) have placed the existence of the effect of dialogical argumentation as an instructional approach on students almost beyond doubt. This is as a result of their own findings on the Toulmin Argumentation Pattern and those of Ogunniyi (2007a & b), Diwu and Ogunniyi (2012) on the use of Contiguity Argumentation Theory in DAIM settings. Other researchers, particularly Scholtz et al. (2007) have been led to similar views in consequence of their findings on pre-service teachers at the same institution where the current study was conducted.



Wandersee and associates have identified a variety of sources of such conceptions, held by learners and teachers, which include parallels from history, use of intuitive rules, prior experience, use of language, and even instruction (Wandersee et al., 1994). And for African science learners such as those who participated in the current study, the use of language was made simple in all instructional materials in light of the view that language plays a significant role in learning (Driver et al., 2000). The findings from the current study provide evidence that corroborates earlier findings in the area of argumentation including those of (Erduran et al., 2004; Jimenez-Aleixandre et al., 2000; Ogunniyi, 2004; 2007a & b; Scholtz et al., 2007; Simon et al., 2006). This work has served to extend earlier research findings into the domain of science (Kim & Pak, 2002; Junkins, 2007; McDermott, 1993; Redish, 2009; Selvaratnam, 2011).

An overview of all these authors' findings indicates that there is consensus among science educators from various institutions that their students have benefited from argumentation as an instructional approach. This approach is credited for having increased their critical reasoning, enabling them to understand science as a way of knowing and behaving. The implication for science education in this regard is that unless this form of thinking is explicitly taught, modelled and supported in the classroom, learners are unlikely to acquire it.

In more exact terms, the extension of the findings from the current study on the use of the DAIM is thus obtained by reflecting on events which took place in the science classroom discussion. With this I conclude Chapter 4 by bringing, as far as possible, an exact insight into the scientific and philosophical point of view of the findings that represent the length and breadth of using the DAIM in his study. A simple consideration in some results and findings in this chapter with respect to the effectiveness of the DAIM shows that the use of DAIM has a multiplicity of benefits. These go in some way to support:

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- the sociocultural perspectives in learning science for non-western science students instilling community of science practice;
 - the ideology of “Ubuntu” which stresses the commonness of purpose that unites all, and sees no differences or ethnicity;
 - exchanges of cognitive discourse in a cooperative learning environment
 - pre-service teachers’ engagement in arguments with no incidence of argumentum ad hominem observed;
 - the relationships and tolerance among students across different ethnic groups throughout the study and beyond group-individual conceptions.

Regarding the last two points, I observed a drastic change in the relationships between the pre-service teachers across race; there is keenness from one student to another to seek help to better their understanding of any phenomenon, which was never the case before. Also, it was observed over time that some pre-service teachers who were poor problem solvers became average problem solvers and few in the ambit of average demonstrated better problem-solvers’ ability. Even so this cannot be said for all the participants.

The study presumes a standard of university education aligned with that of first year pre-service science teachers' ability to use the nature of arguments to solve mathematical problems in physics. I have presented the main ideas in the simplest and most intelligible form, and on the whole, in the sequence and connection in which they actually originated.

In Chapter 5, I present the implications of the findings for teacher education or teacher training institutions, curriculum development and instructional practices.



CHAPTER FIVE

IMPLICATIONS, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In Chapter Four presents the results of data analysis and the findings that addressed the two research questions. This Chapter presents the major findings and their implications for teacher education, curriculum development and instructional practices.

5.2 Major findings and how they answered my research questions

The aim of the study was to explore the effectiveness or otherwise of DAIM, to enhance the ability of first year pre-service teachers to solve mathematical problems in physics. This was done in the anticipation that if successful, it could be used to inform curriculum development efforts and instructional practice as well as provide a viable model for pre-service teacher education programmes in higher institutions in South Africa. In line with this objective, both quantitative and qualitative data were collected, analysed and discussed using argumentation processes within the analytical framework of CAT and DAM. The findings of the study are documented in Chapter 4. In the sections that follow, I shall discuss how answers were sought to the two research questions.

5.2.1 Research question 1: What types of argumentation strategies did the pre-service science teachers use in solving mathematical problems in physics before and after being exposed to a dialogical argumentation instructional model (DAIM)?

In view of my first research question, the following conclusion and implications to the findings are presented as follows:

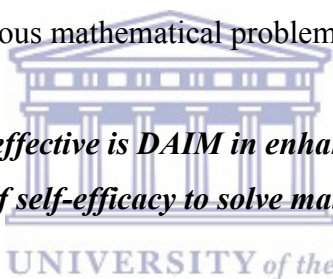
An improvement occurred in the scores, from observation O1 to observation O3 on the pre-service teachers' ability to mobilise mathematical concepts needed to solve physics problems of mechanics. In addition justifiable arguments pertaining to a given problem and its possible solution were observed. There was little or no difference between observations O3 and O4 in terms of the skills displayed by most pre-service teachers. This may be due to what is known as a

ceiling effect. What this means is that majority of pre-service teachers had already doubled their scores around 15-20 marks on both individual and group PSAT activities at observation O3, not leaving much room for improvement on PSAT activities at observation O4.

The pre-service teachers did not improve much in their PSAT performance at observation O4 relative to observation (O3). However they were able to transfer math-in-physics problem-solving skills from group to the individual activity at observation O4 more successfully than at observation O2 or at observation O1. It appears that training in argumentation (DAIM) between the two tests may have prepared the pre-service teachers to learn to transfer these skills from the group activity to the individual activity, as is evident at observations O3 and O4.

The implication of this observation is that training pre-service science teachers on DAIM could facilitate their ability to handle various mathematical problems in physics.

5.2.2 Research question 2: How effective is DAIM in enhancing the pre-service science teachers' ability and sense of self-efficacy to solve mathematical problems in physics?



In using the DAIM for instructional strategies and to determine the pre-service teachers' sense of self-efficacy, only mastery experiences positively predicted pre-service teachers' math-in-physics self-efficacy. By using a Likert scale instrument, findings were presented on a diverged bar chart. It captured pre-service teachers' responses relative to the effectiveness of DAIM and indicated that those with higher frequency of responses agreed that the intervention enhanced their abilities to solve math-in-physics problems. This was in direct contrast with those with lower frequencies. It was also evident in this context that the use of DAIM had influenced the pre-service teachers efficaciously in their learning of given tasks.

5.3. Implications of the findings for teaching and learning of science

The findings from the study have implications for various aspects of the education system: teacher training education as well as basic education (Grades 10-12). For each major finding, I shall provide suggestion(s) on how they could be addressed.

5.3.1 Implication for Teacher education

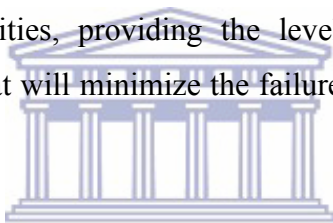
At higher educational institutions, many science programmes are often taught through lectures, demonstrations and practicals, with the emphasis on verification of laws, theories or principles. Current practice in training undergraduate science teachers often only requires an ability to provide definitions of concepts, to perform related calculations and to carry out practicals when necessary. What this means is that tertiary level teaching tends to move from the concrete to more abstract phenomena with little attention to dialogical engagement involving these phenomena. The poignant question is, Should we continue to teach these science concepts without exposing our students to a dialogical discourse about the existing alternate ideas about these phenomena?

In this study, many pre-service teachers demonstrated fallacy in reasoning. Their reasoning was either subsumed by commonsensical knowledge or was scientifically invalid. Some of the pre-service teachers' inability to give scientifically valid explanations indicates that science is not well integrated into their worldview. In terms of CAT their understanding is still largely dominated by their alternative worldview rather than science. This implies either that these have not been effectively addressed in the formal science classes or that they may have been reinforced in the science classes through inadequate use of the terms and the language required for describing scientific phenomena. In this regard, it is evident from these findings that many of the ideas used by the pre-service teachers are still reflected in the thinking of their everyday commonsensical notions, and that most commonly held ideas are remarkably resistant to conceptual change using conventional teaching methods (Wandersee et al., 1994).

Others have suggested that one way for achieving conceptual change is by integrating argumentation skills into instructional activities that involve writing, constructing, and evaluating arguments (Lu & Zhang, 2013). In line with argumentation as a viable method for teaching physics some studies have suggested that through the use of texts that include arguments the refutation of commonsensical notions and misconceptions can be achieved (Duschl et al., 2007; Hynd et al., 1997; Sampson & Clark, 2008).

Educators, lecturers, instructors in teacher training programs are in a unique position to scaffold pre-service science teachers' development as they move from one didactic stage of training to another. The findings on the pre-service teachers' self-efficacy have revealed that mastery experiences positively predicted their math-in-physics self-efficacy. With uniqueness indicators, mastery experiences accounted for a degree of variance between male and female pre-service teachers. The influence of mastery experiences on self-efficacy provides opportunities for science educators to support students' developing self-efficacy beliefs (Bandura, 1997).

Engaging pre-service science teachers in scientific inquiry and problem-solving orientation during their years of training to become professional science teachers will provide mastery experiences necessary to the development of strong science self-efficacy beliefs. Science educators, lecturers and instructors should scaffold these activities, tailoring them to their pre-service teachers' developing abilities, providing the level of challenge that will facilitate efficacy-building successes and that will minimize the failures which could diminish confidence in new abilities.



5.3.2 Implications for Policy and Teachers

The Curriculum and Assessment Policy Statements – CAPS (DoBE, 2012) for Grades 10-12 physical science advances 'critical thinking' as one of its goals, hailing this as potentially highly beneficial to both teachers and learners. The rationale is that 'critical thinking' improves the capacity to learn how to identify and evaluate scientific arguments, as well as to craft them. Also, the CAPS places strong emphasis on understanding the nature of science, technology and phenomena in everyday life. It must be admitted though that this is easier said than done.

As the findings in this and other studies have shown, the pre-service teachers are challenged by having to recognize the grounds of opposing opinions, much more, to undermine them. Thus when their argumentation skills are limited this results in weak rebuttal or inadequate use of the nature of arguments (Berland & Reiser, 2009; Clark et al., 2007; Erduran et al., 2004; Scholtz et al., 2008). But since rebuttals are evidence of the development of cognitive argumentation skills (Kuhn, 1991), this poses pedagogical challenges, in particular, the training of student teachers in argumentation discourse.

In addition to this, other results obtained show that some of the pre-service teachers are weak in evaluating the epistemological characteristics of arguments or what they understand arguments to mean, due to poor reasoning. On this point, Goldstein et al. (2009) suggest that pre-service teachers might have focused on the content of arguments as opposed to their structure. They therefore lack reasoning because they judge the arguments of others based on their own preferences and ignore the epistemic strengths or weaknesses of the arguments themselves (Kuhn, 2005). One way in which this could be addressed is by providing students (pre-service teachers) with further training on argumentation, with tasks that involve the evaluation of arguments and immediate feedback (Larson et al., 2009).

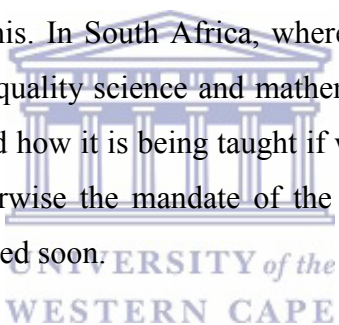
While students' rebuttals may serve to assess the quality of their arguments, these do not necessarily signify a good quality of argument. Hence students' rebuttals do not assume an improved conceptual disposition. They do not represent a tendency to accept or develop a new concept after being dissatisfied with their prior conception of it, resulting from the rebuttal. Questions one dares to ask here are: (1) What does the frequency of rebuttals in argumentation discourse mean to a knower or the one exposed to dialogical argumentation? (2) What has the frequency of rebuttals done to the knower's notion held before and after being exposed to dialogical argumentation? Ascertaining what the student already knows before exposing him or her to dialogic argumentation discourse and teaching him or her accordingly is important. It facilitates the student's understanding and broadens their conceptual disposition after having been exposed to argumentation. The didactic strategies that have been developed as a direct response to the knowledge we now have of students' conceptions of scientific phenomena all involve the students in an early articulation and sharing of these conceptions.

5.3.3 Implications of findings for teaching math-in-physics problem solving

Mathematics is seriously needed for science students since it is the key to the sciences and technology. The concept of the resolution of components (2D motions), for example, is seldom clearly understood by definition alone without mastering the mathematical aspect of it. In terms of math-in-physics, problem-solving errors were found in the works of some pre-service teachers. Hodes and Nolting (1998) describe these as careless conceptual application and procedural errors. A few studies have shown that such problem-solving errors could be resolved

by teaching the pre-service teachers how to create representations of a given problem before trying to solve it (Bing & Redish, 2009; Larkin & Reif, 1979). Also helpful in this regard is recalling knowledge relevant to a given problem (Shin et al., 2003), keeping track of the problem goal (Sherin, 2006), and monitoring whether the results obtained are consistent with other known information (Heller et al., 1992; Mualem & Eylon, 2010). Thus, I believe attempts to address these issues within pre-service teaching programmes could lead to positive change within the learning of school science and the quality of science teachers the faculty will produce in the future.

The use of arguments in the DAIM setting has helped some of the pre-service teachers transfer the skill of analyzing problems critically, for example, labeling problems with different argument tags before attempting to solve them. However, not all the pre-service teachers in their small groups were successful in doing this. In South Africa, where there has been a concerted effort towards increasing the number of quality science and mathematics teachers, it is important that we rethink what is being taught and how it is being taught if we are to inculcate quality teaching and learning of the sciences, otherwise the mandate of the current CAPS on producing good science students might not be realised soon.



5.4 Limitations of the study

In accordance with the delimitation of the study, as stated earlier, this study has evolved from my experience in teaching physical science to pre-service teachers, and hence is limited to one institution. The study is therefore situated in the context of studies that have shown the positive effects of the use of argumentation as a strategy in the science education program. However, the finding might have contributed towards in-service professional development efforts (Erduran & Jimenez-Alexandre, 2008; Ogunniyi & Hewson, 2008), and the development of argumentation skills among science teachers (Braund et al., 2007; Ogunniyi, 2004, 2007a & b; Scholtz et al., 2004 & 2008). It would be ideal to have carried out the study in all four teacher training institutions in the Western Cape Province, but logistical and resource constraints would not permit me to do this. This study limits itself to one institution.

In the design of the study I considered my lecture workload and the students learning. I thus sought a design that would not cause any major disruptions to the pre-service teachers' daily lectures during implementation of the intervention programme and data collection. A four-phase design allowed me to collect sufficient data to address my research questions. Yet the method is also limited in that I could not facilitate all the argumentation lessons and at the same time collect all the data I needed. To take this limitation into consideration I then requested the assistance of science colleagues who helped in facilitating and collecting of data after they were oriented in the study.

Various constraints did not allow me to conduct the study for the entire six months on a non-stop basis. This was due to a two week school holiday soon after the first two observations (O1 and O2) had been completed. This was something beyond my control. However, the need to implement one group time series design over string duration has been pointed out in a number of studies (Kratochwill & Levin, 2010; Lambert, Cartledge, Howard, & Lo, 2006; Shadish & Sullivan, 2011). It takes at least sixteen lectures of thirty-two hours before pre-service teachers get used to this new teaching-learning approach.

I had found that the best time to commence the study was at the beginning of the academic year, in the first semester. The length of tuition time is reasonably longer than the second semester. With first year pre-service teachers coming fresh from high school, there is a willingness to try a new teaching and learning approach, hence the aim of the study. An alternative would have been to conduct the study in the second semester or throughout the two semesters but again these options would have proved impossible due to the nationwide protests across universities in South Africa during the period of the study. Despite these limitations, however, a concerted effort was made to utilize time available to carry out the study.

An additional limitation of this study is the fact that the conclusions drawn from a single case may not lend themselves to generalization as the case would be in experimental design.

Despite these constraints, it was hoped that the findings of the study would provide useful insights into research efforts directed at ameliorating mathematically related problems which

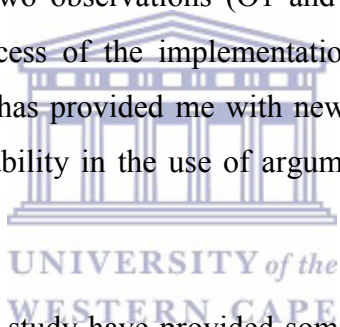
prevent pre-service teachers and those who are already in the teaching profession from solving physics mechanics, 2D motions in an effective manner. Despite these limitations, it is hoped that the study has provided additional insight in terms of the development of science teachers' and students' conceptual understandings of the Nature of Science (Berland & Hammer, 2012a & b; Kuo et al., 2013; Ogunniyi, 2011).

5.6 Conclusion

In this chapter I have presented what I see as the major findings of my study. From my observations there was evidence of pre-service teachers' use of dialogic or collaborative arguments as strategies to mobilize mathematical concepts needed to solve physics problems. There was also an emergence of good use of argumentation skills by many pre-service teachers after the completion of the first two observations (O1 and O2). My methodological findings relate largely to the possible success of the implementation of the dialogical argumentation instructional model DAIM which has provided me with new opportunities for helping the pre-service teachers to develop their ability in the use of argumentation as a strategy for math-in-physics problem solving.

Added to this, the findings of this study have provided some evidence of pre-service teachers' ideas about Newtonian concepts. In the light of these, the views expressed by these pre-service teachers should be instructive to lecturers who are working in the teacher training programmes aimed at preparing Grades 10–12 in physical science. The findings have provided me and my science colleagues with a better idea of the kind of conceptions our students have about Newtonian concepts, including their use of conceptual resources of basic mechanics and the strategies they use to solve related mechanics problems.

Another important conclusion to be made is that argumentation did not lead to a decrease in the amount of content knowledge that had to be covered in a particular topic of physics 1. In short, the use of DAIM appeared to enhance the pre-service teachers' understanding of most of the PSAT activities. Based on this, the use of DAIM has enabled me to identify pre-service teachers' use of the nature of argumentation skills as a problem-solving strategy in learning physics mechanics.



Also, it has offered the pre-service teachers the opportunity to understand the epistemic nature of their own learning of scientific phenomena. At the same time it has helped them to gain much-needed confidence and a sense of self-efficacy when attempting to solve math-in-physics problems. To this end, my analysis has enabled me to identify the kinds of scientific practice that may enable student argumentation to proceed and develop. To illustrate this, the pre-service teachers who focus on the importance of creating tags for the elements of arguments present their work thoughtfully and argue better. It was observed over time that some of the pre-service teachers who were poor problem solvers became average ones and a few in the average zone demonstrated improved ability as problem solvers.

Finally, one of the important key findings relating to the use of the DAIM showed that the pre-service teachers' relationships and tolerance across different ethnic groups throughout the study changed drastically. For example, there was keenness among pre-service teachers to seek help from one another to better their understanding of any phenomenon, which had not been the case before.

These findings led me to conclude that it is possible for the pre-service science teachers to develop their ability and sense of self-efficacy in a multicultural South African science classroom using dialogic or collaborative argumentation as a strategy when solving mathematical problems of basic mechanics in physics.

5.7 Recommendations

A spate of studies has shown that argumentation is increasingly viewed as a leading instructional approach and educational goal for science education both in South Africa and in other countries, especially the use of dialogical or collaborative argumentation as a viable method of teaching science (Diwu & Ogunniyi, 2012; Lubben et al., 2010; Ogunniyi, 2007a & b; Ramogoro & Ogunniyi, 2010; Berland & Reiser, 2010; Evagorou & Osborne, 2013; Kuhn, 2010; McNeill & Pimentel, 2010; Osborne & Patterson, 2011).

The findings of the current study have reaffirmed the importance of argumentation in the science classroom and have extended previous research findings into the domain of physics problem-solving (Kim & Pak, 2002; Junkins, 2007; McDermott, 1993; Redish, 2009; Selvaratnam, 2011). Gauging from the excerpts of arguments, pre-service teachers' views of physics phenomena and explanations differ markedly from current orthodoxy in physics. Their views show similarities with past historical misconceptions in physics coupled with errors in the solutions of problems they attempted to solve. They were susceptible to making conceptual errors, procedural errors, careless errors and so on, which if left unaddressed, during the pre- and in-service teacher education programmes, could seriously hinder their further cognitive learning in physics. Worse still, when they join the science teaching profession, they may simply continue to transmit the erroneous conceptions they held during their teacher training, and the cycle will continue.

Curriculum materials should be developed and used together with teaching strategies such as DAIM to promote the development of conceptual understanding of math-in-physics concepts. Teacher trainers should help pre-service teachers develop an appreciation of a conceptual revolution of any scientific phenomena through collaborative or dialogic argumentation. This can be done by incorporating the DAIM (Ogunniyi, 2009) with CAT (Ogunniyi, 2007a & b) and DAM (Downing, 2007).

Based on the findings of the current study, it seems evident that the DAIM as an instructional strategy has to some extent been beneficial in preparing pre-service teachers to apply their skills to solve math-in-physics problems even in contexts that require different kinds of arguments, including those that I had not previously trained them in. It can also be said that DAIM may not only provide opportunities for pre-service teachers in small groups to evaluate alternative ideas but may also encourage them to use evidence to distinguish between these ideas in a more rational way (Linn & Eylon, 2006; White & Gunstone, 1992). In addition, it may to a large extent provide pre-service teachers with opportunities to examine competing ideas, evaluate the evidence that does or does not support each perspective, and construct arguments justifying the case for one idea or another.

The implication here is that DAIM is a viable method of teaching science which can be used not only in one subject area but in others as well. Moreover, it does not require the often prohibitive financial costs for the implementation of other methods such as technology-based ones. It can therefore be a vital instructional method for changing the way physical science education is taught, if given the attention it deserves, especially in the teaching of math-in-physics problem solving. The constructivist belief in how to teach science is to relate new knowledge to what the students already know (Sherri, 1995). In line with this, many pre-service teachers have expressed the desire to see the DAIM being used as an instructional tool for learning science. Therefore it is worthwhile to give attention to what students would find interesting and helpful in their pursuit of knowledge.

In line with this I believe that cooperative learning is best achieved in an environment in which one's own progress is the progress of others. Put another way, we are because you are. This is the central African worldview theory known as "Ubuntu". The DAIM as espoused by Ogunniyi (2009), draws inspiration from "Ubuntu". The DAIM aims at mitigating the conflicts that often arise in a multicultural science classroom, by providing ample opportunities for dialogue. Thus, the teaching of physics education should not only involve transmitting a set of known facts to pre-service teachers, but should also focus on encouraging them to engage in critical thinking about science concepts, supporting their claims with evidence, and justifying their ideas with practicable explanations (Berland & Reiser, 2009).

It can also be said that a well-organized lecture may lead to efficient presentation of content, but this can bear little relation to its effectiveness for the students as a source for learning math-in-physics problem-solving. It is possible that lecture content is the main definition of the content for learning compared to other instructional approaches that provide students with a cooperative and supportive environment. Such an environment would allow for debate, the nurturing of argumentative skills, discussion, the construction and rectification of misconceptions. Thus the features of such lecture content must ensure quality and innovative didactic discourse, rather than traditional lecture format. Further study should confirm this. Thus, collaborative or dialogic argumentation needs to be taken seriously by curriculum planners, teacher-trainers and science teachers. Better than most other methods, it has the potential to serve as a useful tool in

achieving greater success in the teaching and learning of sciences, and in effecting mathematical problem-solving in physics.

To scaffold argumentation in a didactic discourse, examples should be provided to show students how to rebut, how to achieve or evaluate quality in rebuttals, and how to identify the purpose of rebuttals. Examples should illustrate the use of rebuttals in shaping arguments in the process of problem solving in math-in-physics.

As pointed out earlier, one of the reasons for the pre-service teachers' weak use of rebuttal was their constant use of commonsensical notions. Given this troubling issue, a future study should investigate why the use of nature of arguments produced by pre-service teachers to solve mathematical problems in physics tends to revolve around commonsensical ideas. It would thus be interesting to know whether the conceptual content of pre-service teachers' comments in their use of the nature of arguments to solve mathematical problems in physics is compatible with scientific or commonsensical knowledge. At last, such an investigation could lead to the production of improved teaching methods strongly favouring the development of pre-service teachers' ability to solve mathematical problems in physics efficaciously.

In conclusion, it is my belief that the use of effective instructional strategies such as DAIM could contribute to quality of the teachers produced to implement the CAPS. It is also my hope that the success of pre-service and in-service teacher education, the maintenance of a high level of teacher education qualification, and the provision of adequate teaching practice at universities and schools will help ultimately to actualise the objectives of the new curriculum (CAPS) for Grades 10-12 physical science.

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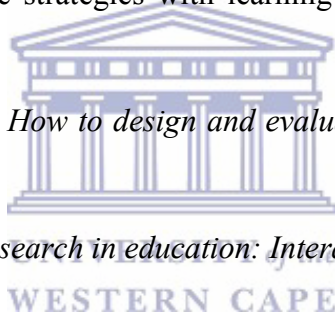
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APPENDICES

APPENDIX A1: PERMISSION LETTER



University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

HOD

Faculty of Education & Social Sciences

Dear Mr. F. Marlie,

Re: Permission to conduct research with first year B.ED physical science students.

This letter seeks your permission to allow me carry out my research with the CPUT, first year B.ED physical science students. I am a registered PhD student in the School of Mathematics and Science Education (with student number 3216726) at the University of the Western Cape. The study is meant to gather data on first year pre-service teachers' ability to solve mathematical problems in physics mechanics (e.g., 2D motions). The data will contribute towards the research findings for my doctoral thesis. It is hoped that the results will give indications/pointers of effective way to overcome the mathematical difficulties that students tend to encounter in solving problems in physics. My research title is:

“An analysis of pre-service teachers’ ability to use a dialogical argumentation instructional model to solve mathematical problems in physics.”

The nature of the study is based on mixed approaches which include quantitative and qualitative (questionnaires and interviews). My data collection will be collected within a semester. I intend to collect the data through the use of:

- 1) Instructional protocol that involves classroom arguments and discussions which can be beneficial to the students in developing/improving their ability to solve mathematical problems in physics.

- 2) Dialogical Argumentation Instructional Model (DAIM) that elucidate cooperative environment and learning opportunities which I believe could help them find effective way to overcome the mathematical difficulties they tend to encounter when solving problems on 2D motions.
- 3) Mechanics (Motions in 2D) data will be collected through the PSAT (Physical Science Achievement Test)
- 4) Interviews that focused on the emerging student learning heuristics and conceptual understanding.

All data collected will be treated with confidentiality and will be used solely for the purposes of the study. For the most important part, students' participation is a matter of choice and no one will be compelled to participate if s/he wishes not to take part.

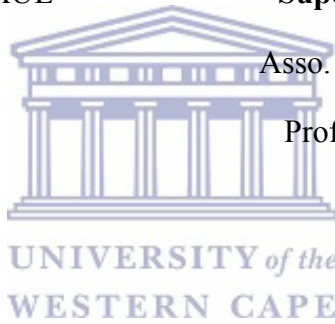
Researcher: IWUANYANWU, PAUL

E-mail: eng.pins@yahoo.com

Supervisors:

Asso. Prof. R. Govender

Prof. M. Ogunniyi



____/____/201[]

Sign: Researcher

APPENDIX A2: LETTER OF INVITATION TO RESEARCH PARTICIPANTS



University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

Dear B.ED physical science (I) students

I write seeking your permission to involve you in my research study. Currently I am pursuing doctoral studies at the University of the Western Cape (UWC) and am about to collect data for my thesis. The study is meant to gather data on your ability to solve mathematical problems in physics mechanics (e.g., 2D motions). The data will contribute towards the research findings for the thesis. It is hoped that the results will give indications/pointers of effective way to overcome the mathematical difficulties that students tend to encounter in solving problems in physical science.

I intend to collect my data through the use of:

- 1) Instructional protocol that involves classroom arguments and discussions which can be beneficial to the students in developing/improving their ability to solve mathematical problems in physics.
- 2) Dialogical Argumentation Instructional Model (DAIM) that elucidate cooperative environment and learning opportunities which I believe could help them find effective way to overcome the mathematical difficulties they tend to encounter when solving problems on 2D motions.
- 3) Mechanics (Motions in 2D) data will be collected through the PSAT (Physical Science Achievement Test)
- 4) Interviews that focused on the emerging student learning heuristics and conceptual understanding.

You will be issued multiple activities (PSAT) at the beginning of the study and are expected to complete them as instructed. And please feel free to write on a separate sheet and be careful to indicate and label question(s) number(s) correctly, if the space provided is not sufficient. The PSAT and interview will be held at the end of the semester.

For all data collected, your confidentiality will be assured and in cases where your contributions may be used for future references or publication, your identities and interests will be protected. Thank you kindly for cooperation in advance.

Researcher: IWUANYANWU, PAUL

E-mail: eng.pins@yahoo.com

Supervisors:

Asso. Prof. R. Govender

Prof. M. Ogunniyi

___/___/201[]

Sign: Researcher



Consent:

I agree to take part in the study and promise to be honest in performing research participant's roles so that the study would fulfil its purposes.

Sign: _____ Date ___/___/201[]
Researcher

Sign: _____ Date ___/___/201[]
Student

APPENDIX B: ETHICAL CLEARANCE-*Institutional Senate Research Committee*

Approval



**UNIVERSITY of the
WESTERN CAPE**

DEPARTMENT OF RESEARCH DEVELOPMENT

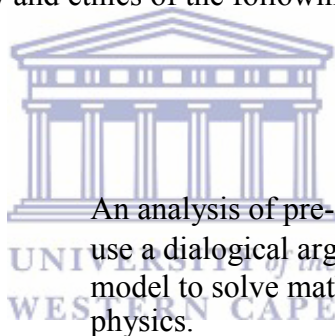
8 December 2015

To Whom It May Concern

I hereby certify that the Senate Research Committee of the University of the Western Cape approved the methodology and ethics of the following research project by:

Mr P Iwuanyanwu (Education)

Research Project:



An analysis of pre-service teachers' ability to use a dialogical argumentation instructional model to solve mathematical problems in physics.

Registration no:

15/7/126

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms. Patricia Josias
Research Ethics Committee Officer

T: +27 21 959 2988/2948. F: +27 21 959 3170
Private Bag X17, Bellville 7535, South Africa
E: pjosias@uwc.ac.za
www.uwc.ac.za

A place of quality,
a place to grow, from hope
to action through knowledge

APPENDIX C: PHYSICAL SCIENCE ACHIEVEMENT TEST (PSAT)

Training prompts to scaffold argumentation

| Construct prompts | Student: What to do |
|--|---|
| What is your answer? Remember to consider: <ul style="list-style-type: none">• What evidence supports your answer?• One of your classmates may disagree with you. What might their alternative be?• What reasons would your classmate provide to support their conclusion?• What would you reply to your classmate to explain your position is right? | Make a logical decision Construct an argument to justify it: <ul style="list-style-type: none">• State facts that provide foundation to your answer• Explain your reasons for not choosing the alternative.• Critique your preferred solution/conclusion • Explain reasons that led to your solution (e.g. rules or principles) that connect the facts you stated. |

Consider the following scenario:

LAS

1. Aviwe pulls a lawnmower with a mass of 50kg across a lawn. His pulling force is 400N at an angle of 50° with the horizontal. Aviwe's father who stood by watching his son asked him:

Aviwe's father: Son, don't you think **pushing** the lawnmower would be much easier than **pulling** it?

Aviwe replied: *No dad, I don't think so. Aviwe made several attempts to justify why he said no, but could not convince his father.*

Aviwe's father: Son, I insist that my suggestion would have been a better way to move the lawnmower across the field. I believe that **pushing** an object is easier than **pulling** it across a horizontal surface.

1.1 What is your view about the suggestion Aviwe's father gave in terms of your scientific understanding?

My/Our view is _____

1.2 One of your classmates may disagree with you. What might their alternative be?

Probably somebody else might think _____

1.3 Explain why you would accept or discard their alternative.

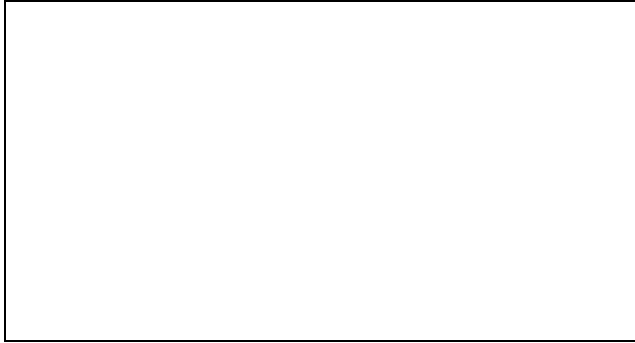
My/Our reason is _____

1.4 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion. **Base on...** _____

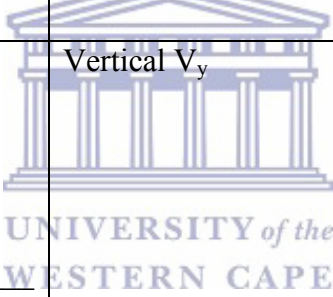
1.5 If we know the horizontal and vertical components V_x and V_y of a vector, then we can find the magnitude and direction of the vector.

If yes, why and if no, why not? _____

1.6 Draw a free-body diagram to show all the components of vector in question 1.



1.7 Calculate the vertical V_y and horizontal V_x components of the vector in question 1.

| Choose a formula if applicable and explain why | Show calculation | |
|--|--|---|
| <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> | <div style="text-align: center;">  <p>Vertical V_y</p> </div> | <div style="text-align: center;"> <p>Horizontal V_x</p> </div> |

1.7.1 Explain reasons that led to your solution (e.g. maths/science rules or principles)

My/Our reason is _____

1.7.2 Are you familiar with problem 1.7? Yes () No ()

2. Consider the following scenario:

Your younger twin siblings both in grade 7 were playing with spring loaded toys (a truck and a car) that can bounce off each other. Amanda picks up a truck and Jim picks up a car that is lighter than the truck. They push them against each other in the center of the living room on the wooden floor ready to let go. Before they do that, you ask: “Which one will get to reach the wall on their side faster?”

Amanda: Mine, the truck.

Jim: Mine, the car.

2.1 Which of your twin siblings do you agree with in terms of your scientific understanding?

Amanda () Jim ()

Why? _____

2.2 One of your classmates may disagree with you. What might their alternative be?

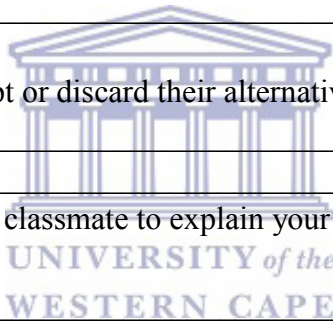
Probably somebody else might think _____

2.3 Explain why you would accept or discard their alternative.

My/Our reason is _____

2.4 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____



3. Everything that moves will eventually come to a stop. Being at rest is the “natural” state of motion of all objects.

3.1 Do you agree or disagree with this notion? _____

3.2 If agree, state why? If disagree, state why?

My/Our reason is _____

3.3 One of your classmates may disagree with you. What might their alternative be?

Probably somebody else might think _____

3.4 Explain why you would accept or discard their alternative.

My/Our reason is _____

3.5 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____

3.6 Figure 1 shows a wooden box with a weight of 100N that is placed on a metal ramp. The coefficient of static friction for the two surfaces in contact is 0,3 and the ramp is inclined at 30° to the horizontal.

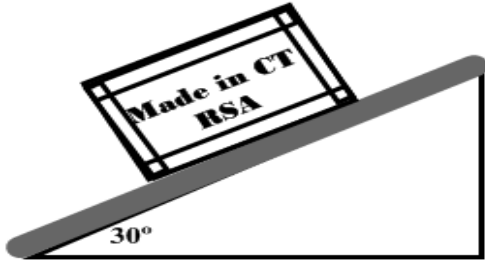
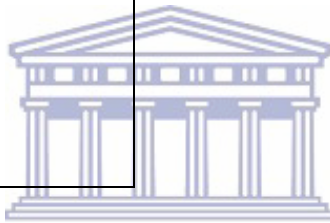


Figure 1

3.6.1 Draw a free-body diagram to show all the forces acting on the wooden box.



3.6.2 Calculate whether the wooden box is in a state of rest.

| Choose a formula if applicable and explain why | Show calculation |
|---|------------------|
| <div style="border-bottom: 1px solid black; margin-bottom: 5px;"></div> <div style="border-bottom: 1px solid black; margin-bottom: 5px;"></div> <div style="border-bottom: 1px solid black; margin-bottom: 5px;"></div> <div style="border-bottom: 1px solid black; margin-bottom: 5px;"></div> | |

3.6.3 Explain reasons that led to your solution in question 3.6.2(e.g. maths/science rules)
My/Our reason is _____

3.6.4 Are you familiar with problem 3.6? Yes () No ()

LAS

4. A continuous force is needed for continuous motion.

4.1 Do you agree or disagree with this notion? _____

4.2 If agree, state why? If disagree, state why?

My/Our reason is _____

4.3 One of your classmates may disagree with you. What might their alternative be?

Probably somebody else might think _____

4.4 Explain why you would accept or discard their alternative.

My/Our reason is _____

4.5 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____

4.6 A block of mass 1 kg is connected to another block of mass 4 kg by a light inextensible string. The system is pulled up a rough plane inclined at 30° to the horizontal, by means of a constant 40N force parallel to the plane as shown in the diagram below.

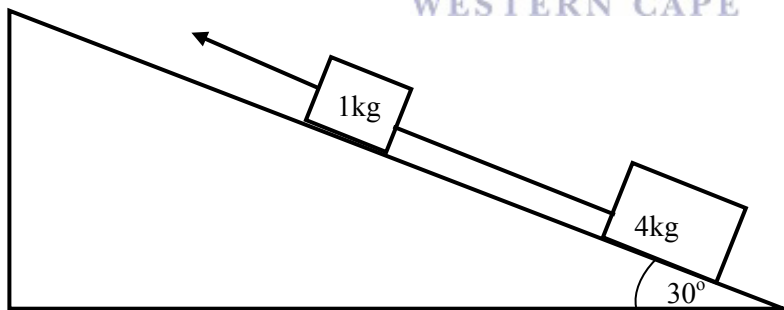


Figure 2

The magnitude of the kinetic frictional force between the surface and the 4 kg block is 10N . The coefficient of kinetic friction between the 1 kg block and the surface is 0,29 .

4.6.1 Draw a labeled free-body diagram showing ALL the forces acting on the 1kg block as it moves up the incline.

4.6.2 Calculate the Tension in the string connecting the two blocks.

| Choose a formula if applicable and explain why | Show calculation |
|--|------------------|
| <hr/> <hr/> <hr/> <hr/> <hr/> | |

4.6.3 Explain reasons that led to your solution in question 4.6.2(e.g. maths/science rules)
My/Our reason is _____

4.6.4 Are you familiar with problem 4.6? Yes () No ()

5. An object is hard to push because it is heavy.



Figure 3

5.1 Do you agree or disagree with this notion? _____

5.2 If agree, state why? If disagree, state why?

My/Our reason is _____

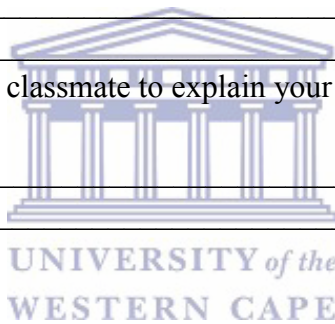
5.3 One of your classmates may disagree with you. What might their alternative be?

5.4 Explain why you would accept or discard their alternative.

My/Our reason is _____

5.5 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____



6. Heavier objects fall faster than lighter ones.

6.1 Do you agree or disagree with this notion? _____

6.2 If agree, state why? If disagree, state why?

My/Our reason is _____



Figure 4

6.3 One of your classmates may disagree with you. What might their alternative be?

Probably somebody else might think _____

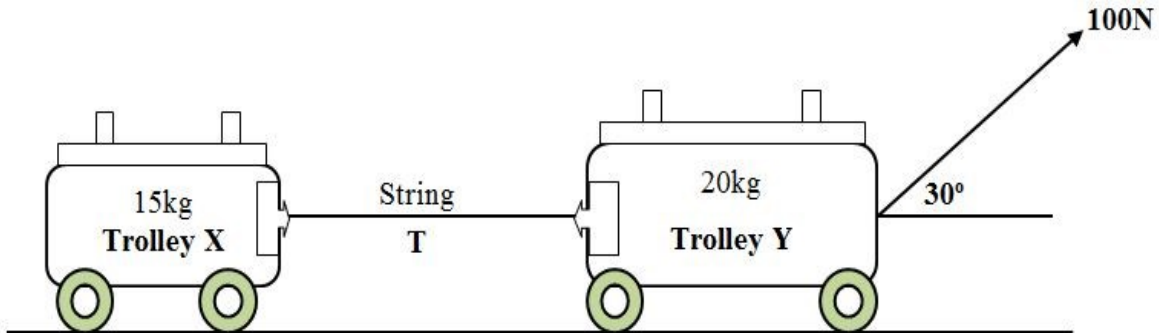
6.4 Explain why you would accept or discard their alternative.

My/Our reason is _____

6.5 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____

6.6 Two trolleys, mass X of 15kg and mass Y of 20kg respectively are connected to each other by means of a string with negligible mass, as shown in the diagram. The 15kg trolley X experiences a frictional force of 5N whereas the 20kg trolley Y has a coefficient of friction of 0.3.



6.6.1 Draw a free-body diagram to show all the horizontal forces acting on each of the trolley.



6.6.2 Calculate the acceleration of the trolley.

| Choose a formula if applicable and explain why | Show calculation |
|--|------------------|
| <hr/> <hr/> <hr/> <hr/> | |

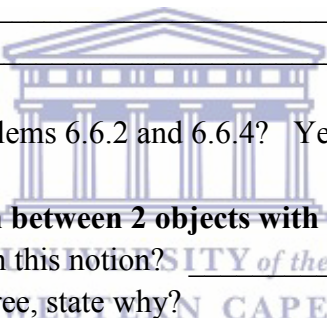
6.6.3 Explain reasons that led to your solution in question 6.6.2(e.g. maths/science rules)
My/Our reason is _____

6.6.4 Calculate the tension T in the string.

| Choose a formula if applicable and explain why | Show calculation |
|---|-------------------------|
| <hr/> <hr/> | |

6.6.5 Explain reasons that led to your solution in question 6.6.4(e.g. maths/science rules)
My/Our reason is _____

6.6.5 Are you familiar with problems 6.6.2 and 6.6.4? Yes () No ()



LAS

7. Gravity is a force of attraction between 2 objects with mass.

7.1 Do you agree or disagree with this notion? _____

7.2 If agree, state why? If disagree, state why? _____

My/Our reason is _____

7.3 One of your classmates may disagree with you. What might their alternative be?

Probably somebody else might think _____

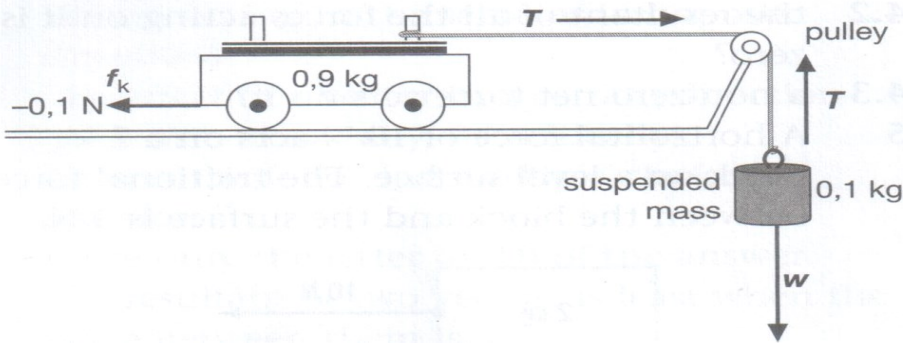
7.4 Explain why you would accept or discard their alternative.

My/Our reason is _____

7.5 What would you reply to your classmate to explain your position is right? Critique your preferred solution/conclusion

Base on ... _____

7.6 Figure 5 shows a trolley that is being accelerated by a falling weight that is connected to it by a light string. The frictional force acting on the trolley is 0,1N.



Assume that the pulley is frictionless.

7.6.1 Draw a free-body diagram to show all the forces acting on the wooden box.

| |
|--|
|  |
|--|

7.6.2 Calculate the acceleration of the trolley.

| Choose a formula if applicable and explain why | Show calculation |
|--|------------------|
| <hr/> <hr/> <hr/> <hr/> <hr/> | |

7.6.3 Explain reasons that led to your solution in question 6.6.2(e.g. maths/science rules)

My/Our reason is _____

7.6.4 Calculate the tension T in the string.

| Choose a formula if applicable and explain why | Show calculation |
|--|------------------|
| <hr/> <hr/> | |

7.6.5 Explain reasons that led to your solution in question 6.6.4(e.g. maths/science rules)
My/Our reason is _____

7.6.5 Are you familiar with problems 7.6.2 and 7.6.4? Yes () No ()

LAS 8. Which of the following **questions (1.6–1.7) or (3.6.1–3.6.2) or (4.6.1 – 4.6.2) or (6.6.1 – 6.6.4) or (7.6.1 – 7.6.4)** did you find difficult to solve? Specify **question number** and explain why.

I/We found item(s) _____

8.1 How did you try to overcome the difficulty?


I/We tried _____

8.2 Mathematical calculation in solving physics problems has always been
 for me because of: _____


| | | | |
|------|--|-----------|--|
| Easy | | Difficult | |
|------|--|-----------|--|

WORKSHEET FOR SMALL GROUP TASKS

Group No:

| Activity | Claim | Grounds (or reasons) Provided |
|--------------------|--|-------------------------------|
| | | |
| | | |
| |  | |
| | UNIVERSITY <i>of the</i> WESTERN CAPE | |
| | | |
| Qualifiers: | | |
| Rebuttals: | | |

WORKSHEET FOR INDIVIDUAL TASKS

| Activity | Claim | Grounds (or reasons) Provided |
|--------------------|--|-------------------------------|
| | | |
| | | |
| |  UNIVERSITY <i>of the</i> WESTERN CAPE | |
| | | |
| | | |
| Qualifiers: | | |
| Rebuttals: | | |

APPENDIX E1: FREQUENCY OF INSTANCES: GROUP CONSTRUCTING AND EVALUATING ARGUMENTS

(Observation Checklist E1)

| Argumentation in Tertiary Physics Classroom (Small group discussion) | Group Constructing And Evaluating Argument (GCEA) → {as espoused in DAM & CAT} | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | A | | | | | B | | | | | C | | | | | D | | | | | E | | | | | F | | | | | G | | | | | H | | | | | | | | | |
| Rating Scale | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Talking and listening to other groups | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Use elements of argument to discuss, solve math-in-physics problem | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Positioning ideas using well articulated multiple view points | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Justifying with evidence using correct (rules/principles of math-in-physics) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Construct arguments by using writing frames to present ideas | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Evaluate arguments-content/nature of evidence that resulted group's solution to math-in-physics problem | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Frequent counter-arguing to strengthen either own group's views or other groups | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reflecting on argument process, group/individual resolving anomalies – embracing conceptual change. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PRE-TEST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| POST-TEST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Appendices E1 & E2 (Explanation): Group Constructing and Evaluating Argument (GCEA)

The Rating Scales [Observation checklist E1]

The 5-point rating scale shows the frequency of actions taking place. The numbering scale does not conform to a negative judgment of the quality of actions display by the pre-service teachers. Neither does it target who wins or who loses. Rather it represents the frequency of the pre-service teachers' engagements in the argumentative discourse of small groups. It also orchestrates the manner of their adaptability to the elements of arguments as well as the level of each group's involvement. The meanings of the numbers are:

- 1 – Not at all
- 2 – Occasionally
- 3 – Some of the time
- 4 – A lot of the time
- 5 – Frequently



Identification of nature of argument [Observation checklist E2]

The 7-point numbering shows the manner of argument taking place. It is categorized according to the purpose of the study, the research questions, in particular, the first research question to identify the nature of argumentation strategies that pre-service science teachers use to solve selected mathematical problems in physics, and hence the quality thereof as espoused by Toulmin (1958/2006) in the extant literature. Given the definition of argumentation in the extant literature, it can be defined as the process of making a claim and providing justifications for the claim using evidence". Fundamentally, we make: a claim (C), we must justify the claim so we need data (D) as well as evidence, warrant (W). If our claim attracted challenge, we further need backing (B) against rebuttal (R). It must be pointed out that the numbering (1 – 7) does not represent strength of argument, but the manner in which it occur. Thus, the ratings are necessarily fundamental. The meanings of the numbers are:

- 1 – claim-data [CD]
- 2 – claim-warrant [CW]
- 3 – claim-data-warrant [CDW]
- 4 – claim-data-warrant-backing [CDWB]
- 5– claim-data-rebuttal [CDR]
- 6– claim-warrant-rebuttal [CWR]
- 7– claim-data-warrant-rebuttal [CDWR]

APPENDIX E2: Observation Checklist-Elements of Arguments→Observations (O1-O2)

| Argumentation in Tertiary Physics Classroom (Small group discussion) | | Group Constructing And Evaluating Argument (GCEA) Instruction Approach: <i>Dialogical Argumentation Instructional Model (DAIM)</i> | | | | | | | |
|--|-----------------|---|-------|-------|-------|-------|-------|-------|-------|
| Group | | A | B | C | D | E | F | G | H |
| Tally | Elements of TAP | O1-O2 | O1-O2 | O1-O2 | O1-O2 | O1-O2 | O1-O2 | O1-O2 | O1-O2 |
| | CD | | | | | | | | |
| | CW | | | | | | | | |
| | CDW | | | | | | | | |
| | CDWB | | | | | | | | |
| | CDR | | | | | | | | |
| | CWR | | | | | | | | |
| | CDWR | | | | | | | | |

[Key: CD-claim-data, CW-claim-warrant, CDW-claim-data-warrant, CDWB-claim-data-warrant-backing, CDR-claim-data-rebuttal, CWR-claim-warrant-rebuttal, CDWR-claim-data-warrant-rebuttal; O1-O2-Observations pair. The total number of items that can possibly yield arguments in the PSAT instrument is 48. Ideally to properly record the number of times the elements of argument are used by individual/group, the ‘tally’ recording format is necessary.

APPENDIX E3: Observation Checklist: Elements of Arguments→Observations (O3-O4)

| Argumentation in Tertiary Physics Classroom (Small group discussion) | | Group Constructing And Evaluating Argument (GCEA) Instruction Approach: <i>Dialogical Argumentation Instructional Model (DAIM)</i> | | | | | | | |
|--|-----------------|---|-------|-------|-------|-------|-------|-------|-------|
| Group | | A | B | C | D | E | F | G | H |
| Tally | Elements of TAP | O3-O4 | O3-O4 | O3-O4 | O3-O4 | O3-O4 | O3-O4 | O3-O4 | O3-O4 |
| | CD | | | | | | | | |
| | CW | | | | | | | | |
| | CDW | | | | | | | | |
| | CDWB | | | | | | | | |
| | CDR | | | | | | | | |
| | CWR | | | | | | | | |
| | CDWR | | | | | | | | |

[Key: CD-claim-data, CW-claim-warrant, CDW-claim-data-warrant, CDWB-claim-data-warrant-backing, CDR-claim-data-rebuttal, CWR-claim-warrant-rebuttal, CDWR-claim-data-warrant-rebuttal; O3-O4-Observations pair] *The total number of items that can possibly yield arguments in the PSAT instrument is 48. Ideally to properly record the number of times the elements of argument are used by individual/group, the ‘tally’ recording format is necessary.*

Appendix E4: Observation Checklist-Elements of Arguments→O1-O2 & O3-O4 levels)

| Argumentation in Tertiary Physics Classroom (Small group discussion) | Group Constructing And Evaluating Argument (GCEA) Instruction Approach: <i>Dialogical Argumentation Instructional Model</i> (DAIM) | | | | | | | | | | | | | | | | |
|---|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---|
| | Group | | A | | B | | C | | D | | E | | F | | G | | H |
| Elements of | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | O1-O2 | O3-O4 | |
| TAP | | | | | | | | | | | | | | | | | |
| CD | | | | | | | | | | | | | | | | | |
| CW | | | | | | | | | | | | | | | | | |
| CDW | | | | | | | | | | | | | | | | | |
| CDWB | | | | | | | | | | | | | | | | | |
| CDR | | | | | | | | | | | | | | | | | |
| CWR | | | | | | | | | | | | | | | | | |
| CDWR | | | | | | | | | | | | | | | | | |

[Key: CD-claim-data, CW-claim-warrant, CDW-claim-data-warrant, CDWB-claim-data-warrant-backing, CDR-claim-data-rebuttal, CWR-claim-warrant-rebuttal, CDWR-claim-data-warrant-rebuttal; O1-observation 1, O2-observation 2, O3-observation 3, and O4-observation 4]. The total number of items that can possibly yield arguments in the PSAT instrument is 48. Ideally to properly record the number of times the elements of TAP are used by individual/group, the 'tally' recording format is necessary.

APPENDIX F: EFFECTIVENESS OF USING DIALOGICAL ARGUMENTATION INSTRUCTIONAL MODEL (DAIM)

How have your experiences in the DAIM based-lectures improved your ability in using the nature of arguments to solve mathematical problems in physics mechanics e.g. Motions in 2D?

| Responses & Points (Items) | Strongly disagree | Somewhat disagree | Neither agree <i>nor</i> disagree | Somewhat agree | Strongly agree |
|--|-------------------|-------------------|-----------------------------------|----------------|----------------|
| | (1) | (2) | (3) | (4) | (5) |
| 1. DAIM has helped me realize the value of working in groups to achieve common objective, which in turn enhances individual ability | | | | | |
| 2. DAIM based-lectures have enhanced my efficacy (ease and confidence) to learn controversial science phenomena | | | | | |
| 3. DAIM has helped me to use the nature of arguments as strategies to enhance my math-in-physics problem-solving ability | | | | | |
| 4. DAIM is an effective instructional tool for learning science in a multicultural classroom. It provides the opportunity for learners to interact with each other, express their views freely and to respect/value different views from others. | | | | | |
| 5. DAIM has helped me to acquire more math-in-physics skills (e.g., by working in small groups we were able to resolved anomalies, exchange ideas and reached conceptual fruitfulness after dissatisfaction with our prior knowledge). | | | | | |
| 6. DAIM has empowered me on how to tap into qualitative understanding of math-in-physics problems before applying algebraic formalism. This empowerment came from watching other members of my group perform problem-solving routine check, search and identify key concepts of the problem in question, brainstorm for problem recognition, gather known and unknown quantities and chose/construct an appropriate formula to solve the problem. | | | | | |
| 7. The positive aspects of DAIM include hearing a diversity of perspectives and knowledge bases. Negative aspects include, among others, the temptation to digress from the topic in question. | | | | | |
| 8. Before I was exposed to DAIM, I didn't know there are such things as elements of argument, e.g., claim, data, warrant, rebuttal, backing and qualifier (for TAP). Neither did I know when a particular idea/construct is dominant, suppressed, emergent, assimilated or equipollent (for CAT). Nor that I know all claims should be reasoned and justified. I used to argue and talk at others, but after being exposed to DAIM, I learned the nature of arguments and how to tabulate my argument. | | | | | |
| 9. The frames gained from DAIM have helped me to define more clearly the interconnectedness of seemingly dichotomized concepts in science and their everyday notion. | | | | | |
| 10. As a pre-service teacher who will later teach the science to learners when I have qualified, DAIM based-lectures has equipped me with the necessary instructional skills to engage in argumentation on any issue be it in the science classroom or outside. | | | | | |

APPENDIX G: INTERVIEW QUESTIONS

QUESTION 1

How have your experiences in the DAIM based-lectures improved your ability in using the nature of arguments to solve mathematical problems in physics mechanics e.g. Motions in 2D?

Sub-questions:

- 1.1 Do you think the DAIM has equipped you on how to tap into qualitative understanding of math-in-physics problems, say 2D-motions using the nature of arguments before applying algebraic manipulation?

- 1.2 What would you say are the positive and negative aspects of the use of DAIM as an instructional approach?

QUESTION 2

How confident and ease are you NOW with math-in-physics problem-solving in mechanics, say 2D motions compare BEFORE the intervention programme (DAIM)?

2.1 If you have to rate yourself on a scale of confident and comfortableness with math-in-physics problems (e.g., 2D-motions). How would you rate yourself?

- 1 – Nothing has changed for me
- 2 – I'm neither comfortable nor at ease
- 2 – I am somewhat comfortable and at ease
- 3 – I am comfortable and at ease
- 5 – I am very comfortable and at ease

2.2 From your question 2.1 response, what would you say is responsible to your present confident and comfortableness to solve math-in-physics problems?

QUESTION 3

Effectiveness of any instructional model is often based on how well it helps the learners (in this case you) to learn presented activities meaningfully by achieving desired goals and objectives of the activities. Base on this explanation, one can assume DAIM has been effective. If Yes, Why? If No, Why Not?

APPENDIX H: Responses -Items Sought For Math-In-Physics Problem Recognition

| GROUP | Y/N | Observation pair | Observation pair | Observation pair | Observation pair |
|--|--|------------------|------------------|------------------|------------------|
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 1 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 2 | 1 | 1 |
| Group A | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 1 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 2 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 1 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 2 | 1 | 1 |
| | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 1 | 1 | 1 |
| Group B | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 1 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 2 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 2 | 1 | 1 |
| | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 2 | 1 | 1 |
| Group C | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 1 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 2 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 1 | 1 | 1 |
| Group D | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 1 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 2 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 1 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 2 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 1 | 1 | 1 |
| Group E | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 1 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 2 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 2 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 2 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 2 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 1 | 1 | 1 |
| Group F | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 2 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 1 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 2 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 2 | 1 | 1 |
| Group G | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 1 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 1 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |
| Qs: YES/NO ANSWER [YES = 1, NO = 2] | | | | | |
| | 1.5 Are you familiar with (V_x & V_y)? | Y/N | 1 | 1 | 1 |
| | 1.7.2 Are you familiar with problem (1.7)? | Y/N | 1 | 1 | 1 |
| Group H | 3.6.4 Are you familiar with problem (3.6)? | Y/N | 2 | 1 | 1 |
| | 4.6.4 Are you familiar with problem (4.6)? | Y/N | 1 | 1 | 1 |
| | 6.6.5 Are you familiar with problem (6.6.4)? | Y/N | 2 | 1 | 1 |
| | 7.6.5 Are you familiar with problem (7.6.2 & 7.6.4)? | Y/N | 1 | 1 | 1 |



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