

**First year university students' conceptual understanding of  
electric circuits**

**by**

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degree**

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### **FIRST-YEAR UNIVERSITY STUDENTS' CONCEPTUAL UNDERSTANDING OF ELECTRIC CIRCUITS**

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## Dedication

This study is dedicated to:

*My supervisors who supported me,*

*My family who endured me,*

*My husband who put up with me,*

*My grandfather who would have been so proud of me, and*

*My Saviour who died for me.*

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## Abstract

This dissertation reports on the secondary analysis of data obtained in 2013 about first-year university student's conceptual understanding of concepts related to simple DC-circuits. The aim was to investigate the nature of conceptual understanding of students entering first-year physics at a South African university, and to explore how their conceptual understanding relates to contextual factors.

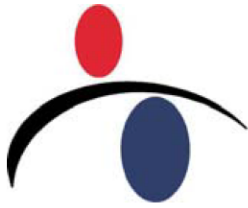
Data collected from 815 participants comprise contextual data about each participant and responses in the DIRECT-instrument (**D**etermining and **I**nterpreting **R**esistive **E**lectric **C**ircuits **C**oncepts **T**est). The conceptual framework for this study was based on a combination of the model about the effectiveness of science teaching and the critical outcomes related to electricity and electric circuits, which involve aspects of current, energy, potential difference and the physical aspects of circuits. The contextual data included information at personal, classroom and school level. Data were analysed using Rasch analysis.

The study found that students entering a first-year physics module at a South African university have poor conceptual understanding about simple DC-electric circuits. The analysis of the DIRECT-instrument revealed that students had difficulties understanding concepts relating to parallel circuits, confusing terms such as voltage and current, and current and energy. They also struggled to relate a circuit diagram to an actual circuit and issues regarding short circuits were prominent.

The analysis of the contextual data revealed that students' degree of exposure to practical work does not imply conceptual understanding of DC-electric circuits. Factors that relate with conceptual understanding included students' attitudes towards science, gender and previous achievement in Science, Mathematics, and English.

**Key terms:** *Conceptual understanding, DC-electric circuit, Misconception, Aptitudes*

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## List of abbreviations

|           |                                                                        |
|-----------|------------------------------------------------------------------------|
| ANOVA     | Analysis of variance                                                   |
| CAPS      | Curriculum Assessment Policy Statement                                 |
| DC        | Direct Current                                                         |
| DIF       | Differential Item Functioning                                          |
| DIRECT    | Determining and Interpreting Resistive Electric Circuits Concepts Test |
| DoBE      | Department of Basic Education                                          |
| FET       | Further Education Training                                             |
| ICC       | Item Characteristic Curve                                              |
| OBE       | Outcomes Based Education                                               |
| NCS       | National Curriculum Statement                                          |
| NSC       | National Senior Certificate                                            |
| PIRLS     | Progress in International Reading Literacy Study                       |
| PSI       | Person Separation Index                                                |
| RUMM 2020 | Rasch Unidimensional Measurement Model                                 |
| SD        | Standard Deviation                                                     |
| SMTe      | Science, Mathematics and Technology education                          |
| TIMSS     | Trends in International Mathematics and Science Study                  |

## Table of Contents

|                                    |      |
|------------------------------------|------|
| DECLARATION .....                  | I    |
| TITLE OF THE PROPOSED STUDY .....  | II   |
| ETHICAL CLEARANCE CERTIFICATE..... | III  |
| DEDICATION .....                   | IV   |
| ACKNOWLEDGEMENTS.....              | V    |
| ABSTRACT .....                     | VI   |
| LANGUAGE EDITOR .....              | VII  |
| LIST OF ABBREVIATIONS.....         | VIII |
| TABLE OF CONTENTS.....             | IX   |
| LIST OF FIGURES.....               | XIII |
| LIST OF TABLES .....               | XVI  |
| LIST OF ANNEXURES .....            | XVII |

### CHAPTER 1:

#### INTRODUCTION AND CONTEXTUALISATION OF THE STUDY

|       |                                          |    |
|-------|------------------------------------------|----|
| 1.1   | Introduction .....                       | 1  |
| 1.2   | Background and Problem Statement.....    | 1  |
| 1.3   | Rationale and Purpose of the Study ..... | 3  |
| 1.4   | Research Question .....                  | 6  |
| 1.4.1 | Primary research question .....          | 7  |
| 1.4.2 | Secondary research questions .....       | 7  |
| 1.5   | Potential Benefits of this Study .....   | 8  |
| 1.6   | Limitations of this Study.....           | 9  |
| 1.7   | Core Concepts of the Study .....         | 9  |
| 1.7.1 | Conceptual understanding.....            | 9  |
| 1.7.2 | Misconception.....                       | 10 |
| 1.7.3 | DC -circuit.....                         | 10 |
| 1.7.4 | Aptitudes.....                           | 10 |
| 1.8   | Structure of the Dissertation .....      | 10 |

### CHAPTER 2:

#### LITERATURE REVIEW

|       |                                                                                           |    |
|-------|-------------------------------------------------------------------------------------------|----|
| 2.1   | Introduction .....                                                                        | 12 |
| 2.2   | Electricity and Electrical Circuits.....                                                  | 13 |
| 2.2.1 | General issues that may hinder the effective learning of simple DC-electric circuits..... | 13 |

|            |                                                                                                             |           |
|------------|-------------------------------------------------------------------------------------------------------------|-----------|
| 2.2.2      | Why learning about electric circuits may be difficult.....                                                  | 15        |
| 2.2.3      | Conceptual concerns when teaching and learning electric circuits .....                                      | 17        |
| <b>2.3</b> | <b>Conceptual Understanding of Simple DC-Electric Circuits.....</b>                                         | <b>18</b> |
| <b>2.4</b> | <b>Published Tests Determining Conceptual Understanding of DC-Electric Circuits.....</b>                    | <b>21</b> |
| 2.4.1      | Different types of questionnaires .....                                                                     | 21        |
| 2.4.2      | The DIRECT-instrument as a diagnostic test .....                                                            | 24        |
| 2.4.2.1    | Validity when generating test-scores .....                                                                  | 26        |
| 2.4.2.2    | Reliability when generating test-scores .....                                                               | 26        |
| <b>2.5</b> | <b>Contextual Factors Known to Relate to Students' Conceptual Understanding of Scientific Concepts.....</b> | <b>27</b> |
| <b>2.6</b> | <b>Conceptual Framework .....</b>                                                                           | <b>32</b> |
| <b>2.7</b> | <b>Conclusion.....</b>                                                                                      | <b>36</b> |

## CHAPTER 3: METHODOLOGY

|             |                                                          |           |
|-------------|----------------------------------------------------------|-----------|
| <b>3.1</b>  | <b>Introduction .....</b>                                | <b>37</b> |
| <b>3.2</b>  | <b>Research Methodology .....</b>                        | <b>37</b> |
| <b>3.3</b>  | <b>Research Design .....</b>                             | <b>39</b> |
| <b>3.4</b>  | <b>Sample Selection .....</b>                            | <b>40</b> |
| <b>3.5</b>  | <b>The DIRECT-Instrument .....</b>                       | <b>41</b> |
| 3.5.1       | Outcomes and objectives of the DIRECT -instrument .....  | 42        |
| 3.5.2       | Cognitive levels involved in the DIRECT-instrument ..... | 43        |
| 3.5.3       | Misconceptions revealed by the DIRECT-instrument .....   | 45        |
| 3.5.4       | The SA curriculum and the DIRECT-instrument .....        | 46        |
| <b>3.6</b>  | <b>The Biographical Questionnaire .....</b>              | <b>46</b> |
| <b>3.7</b>  | <b>Data Collection.....</b>                              | <b>48</b> |
| 3.7.1       | Data collection .....                                    | 48        |
| <b>3.8</b>  | <b>Data Analysis – The Rasch Model .....</b>             | <b>48</b> |
| <b>3.9</b>  | <b>Quality Criteria .....</b>                            | <b>51</b> |
| 3.9.1       | Validity .....                                           | 51        |
| 3.9.2       | Reliability.....                                         | 52        |
| <b>3.10</b> | <b>Ethical Considerations.....</b>                       | <b>52</b> |
| <b>3.11</b> | <b>Conclusion.....</b>                                   | <b>53</b> |

## **CHAPTER 4: PERFORMANCE IN THE OBJECTIVES OF THE DIRECT-INSTRUMENT: RESULTS, ANALYSIS, AND INTERPRETATION**

|            |                                                                   |            |
|------------|-------------------------------------------------------------------|------------|
| <b>4.1</b> | <b>Introduction .....</b>                                         | <b>54</b>  |
| <b>4.2</b> | <b>The Diagnostic Instrument .....</b>                            | <b>55</b>  |
| <b>4.3</b> | <b>Test Statistics .....</b>                                      | <b>56</b>  |
| <b>4.4</b> | <b>Rasch Analysis: Validity and Reliability.....</b>              | <b>61</b>  |
| 4.4.1      | Overall fit.....                                                  | 62         |
| 4.4.2      | Analysis of items in terms of item location and fit residual..... | 66         |
| 4.4.3      | Discussion of items excluded from the Rasch analysis. ....        | 67         |
| 4.4.4      | Discussion of the improved overall fit.....                       | 71         |
| 4.4.5      | Response dependence .....                                         | 72         |
| <b>4.5</b> | <b>Discussion of Performance .....</b>                            | <b>75</b>  |
| 4.5.1      | Item Characteristic Curves .....                                  | 76         |
| 4.5.2      | Discussion of Items .....                                         | 77         |
| 4.5.3      | Summary of students' misconceptions revealed by the test .....    | 112        |
| <b>4.6</b> | <b>Chapter Summary .....</b>                                      | <b>115</b> |

## **CHAPTER 5: EXPLORING THE RELATIONSHIP BETWEEN CONTEXTUAL FACTORS AND LEARNER PERFORMANCE: RESULTS, ANALYSIS AND INTERPRETATION**

|            |                                                           |            |
|------------|-----------------------------------------------------------|------------|
| <b>5.1</b> | <b>Introduction .....</b>                                 | <b>118</b> |
| <b>5.2</b> | <b>The Biographical Questionnaire .....</b>               | <b>118</b> |
| <b>5.3</b> | <b>Overview of Contextual Data .....</b>                  | <b>121</b> |
| 5.3.1      | Engineering group .....                                   | 121        |
| 5.3.2      | B.Sc. Physical Sciences group .....                       | 122        |
| 5.3.3      | B.Sc. Biological Sciences.....                            | 122        |
| 5.3.4      | B.Sc Extended Program .....                               | 123        |
| <b>5.4</b> | <b>Reliability Analysis .....</b>                         | <b>125</b> |
| 5.4.1      | Cronbach's coefficient alpha.....                         | 125        |
| 5.4.2      | Unidimensionality and differential Item functioning ..... | 126        |
| 5.4.3      | Person frequency distribution and analysis .....          | 128        |
| <b>5.5</b> | <b>Chapter Summary .....</b>                              | <b>140</b> |

## **CHAPTER 6: CONCLUSION**

|            |                                                                  |            |
|------------|------------------------------------------------------------------|------------|
| <b>6.1</b> | <b>Introduction .....</b>                                        | <b>144</b> |
| <b>6.2</b> | <b>Overview of the Study.....</b>                                | <b>145</b> |
| <b>6.3</b> | <b>Answering the Research Questions .....</b>                    | <b>150</b> |
| 6.3.1      | Research sub-question 1.....                                     | 149        |
| 6.3.2      | Research sub-question 2 .....                                    | 155        |
| 6.3.3      | Primary research question .....                                  | 158        |
| <b>6.4</b> | <b>Reflection on the Conceptual Framework of the Study .....</b> | <b>162</b> |
| <b>6.5</b> | <b>Limitations of the Study .....</b>                            | <b>164</b> |
| <b>6.6</b> | <b>Recommendations for Future Study.....</b>                     | <b>165</b> |
| <b>6.7</b> | <b>Conclusions and Implications .....</b>                        | <b>166</b> |

|                                 |            |
|---------------------------------|------------|
| <b>LIST OF REFERENCES .....</b> | <b>168</b> |
|---------------------------------|------------|

## ***ANNEXURES***

|            |                                                                  |            |
|------------|------------------------------------------------------------------|------------|
| <b>7.1</b> | <b>ANNEXURE A Biographical Questionnaire .....</b>               | <b>184</b> |
| <b>7.2</b> | <b>ANNEXURE B DIRECT-instrument.....</b>                         | <b>187</b> |
| <b>7.3</b> | <b>ANNEXURE C Curriculum Content: NCS vs CAPS.....</b>           | <b>196</b> |
| <b>7.4</b> | <b>ANNEXURE D Illustration of Common Misconceptions .....</b>    | <b>199</b> |
| <b>7.5</b> | <b>ANNEXURE E Assessment Framework: Test-items .....</b>         | <b>206</b> |
| <b>7.5</b> | <b>ANNEXURE F Assessment Framework: Contextual factors .....</b> | <b>207</b> |

## List of Figures

|                |                                                                                        |    |
|----------------|----------------------------------------------------------------------------------------|----|
| Figure 1.1:    | Performance distribution curves 2011 -2014 in Physical Science. ....                   | 2  |
| Figure 1.2:    | Performance distribution curves 2014 – 2018 in Physical Science. ..                    | 2  |
| Figure 2.1:    | Objectives tested for with the aid of the diagnostic instrument.....                   | 25 |
| Figure 2.2:    | Conceptual framework designed to fit with the aim of the study.....                    | 35 |
| Figure 3.1:    | Alignment between research questions, methodology, and<br>instruments.....             | 38 |
| Figure 3.2:    | Roles and steps involved within a cross-sectional quantitative<br>research design..... | 40 |
| Figure 3.3:    | Misconceptions associated with the four test objectives. ....                          | 46 |
| Figure 4.1:    | Distribution of participants' performance on the DIRECT-instrument                     | 58 |
| Figure 4.2:    | Summary statistics for the test and the sample.....                                    | 64 |
| Figure 4.3:    | Individual item fit residuals. ....                                                    | 65 |
| Figure 4.4:    | Test-item 14 (Correct option: B). ....                                                 | 68 |
| Figure 4.5:    | Test-item 16 (Correct option: C). ....                                                 | 69 |
| Figure 4.6:    | Test-item 20 (Correct option: D). ....                                                 | 70 |
| Figure 4.7:    | Test-item 28 (Correct Option: D). ....                                                 | 71 |
| Figure 4.8:    | Summary statistics after excluding test-items .....                                    | 72 |
| Figure 4.9:    | Response dependence as calculated through RUMM2020 .....                               | 74 |
| Figure 4.10:   | Item-map excluding non-fitting items 14, 16, 20 & 28. ....                             | 75 |
| Figure 4.11.1: | ICC for test-item 1 .....                                                              | 77 |
| Figure 4.11.2: | test-item 1 .....                                                                      | 77 |
| Figure 4.12.1: | ICC for test-item 2. ....                                                              | 78 |
| Figure 4.12.2: | Test-item 2.. ....                                                                     | 78 |
| Figure 4.13.1: | ICC for test-item 3. ....                                                              | 80 |
| Figure 4.13.2: | Test-item 3. ....                                                                      | 80 |
| Figure 4.14.1: | ICC for test-item 4. ....                                                              | 81 |
| Figure 4.14.2: | Test-item 4.. ....                                                                     | 81 |
| Figure 4.15.1: | ICC for test-item 5. ....                                                              | 83 |
| Figure 4.15.2: | Test-item 5. ....                                                                      | 83 |
| Figure 4.16.1: | ICC for test-item 6. ....                                                              | 84 |
| Figure 4.16.2: | Test-item 6. ....                                                                      | 84 |
| Figure 4.17.1: | ICC for test-item 7. ....                                                              | 85 |

|                                           |     |
|-------------------------------------------|-----|
| Figure 4.17.2: Test-item 7 .....          | 85  |
| Figure 4.18.1: ICC for test-item 8. ....  | 86  |
| Figure 4.18.2: Test-item 8 .....          | 86  |
| Figure 4.19.1: ICC for test-item 9. ....  | 87  |
| Figure 4.19.2: Test-item 9. ....          | 87  |
| Figure 4.20.1: ICC for test-Item 10. .... | 89  |
| Figure 4.20.2: Test-Item 10. ....         | 89  |
| Figure 4.21.1: ICC for test-item 11. .... | 90  |
| Figure 4.21.2: Test-item 11 .....         | 90  |
| Figure 4.22.1: ICC for test-item 12. .... | 91  |
| Figure 4.22.2: Test-item 12. ....         | 91  |
| Figure 4.23.1: ICC for test-item 13. .... | 92  |
| Figure 4.23.2: Test-item 13. ....         | 93  |
| Figure 4.24.1: ICC for test-item 15. .... | 95  |
| Figure 4.24.2: Test-item 15. ....         | 94  |
| Figure 4.25.1: ICC for test-item 17. .... | 96  |
| Figure 4.25.2: Test-item 17. ....         | 96  |
| Figure 4.26.1: ICC for test-item 18. .... | 97  |
| Figure 4.26.2: Test-item 18 .....         | 97  |
| Figure 4.27.1: ICC for test-item 19. .... | 99  |
| Figure 4.27.2: Test-item 19. ....         | 99  |
| Figure 4.28.1: ICC Test-item 21. ....     | 100 |
| Figure 4.28.2: Test-item 21 .....         | 100 |
| Figure 4.29.1: ICC for test-item 22. .... | 100 |
| Figure 4.29.2: Test-item 22. ....         | 101 |
| Figure 4.30.1: ICC for test-item 23. .... | 103 |
| Figure 4.30.1: Test-item 23. ....         | 103 |
| Figure 4.31.1: ICC for test-item 24. .... | 105 |
| Figure 4.31.2: Test-item 24. ....         | 105 |
| Figure 4.32.1: ICC for test-item 25. .... | 107 |
| Figure 4.32.2: Test-item 25 .....         | 105 |
| Figure 4.33.1: ICC for test-item 26. .... | 108 |
| Figure 4.33.2: Test-item 26 .....         | 108 |
| Figure 4.34.1: ICC for test-item 27. .... | 109 |

|                                                                                             |     |
|---------------------------------------------------------------------------------------------|-----|
| Figure 4.34.2: Test-item 27. ....                                                           | 109 |
| Figure 4.35.1: ICC for test-item 29. ....                                                   | 111 |
| Figure 4.35.2: Test-item 29 .....                                                           | 111 |
| Figure 5.1: ANOVA and Mean person locations for the SCHOOL contextual<br>factor .....       | 127 |
| Figure 5.2.1: Person Frequency Distribution Graph - Type of school attended....             | 130 |
| Figure 5.2.2: Person Frequency Distribution Curve - Physical Science Average                | 130 |
| Figure 5.2.3: Person Frequency Distribution Curve - Mathematics Average.....                | 130 |
| Figure 5.2.4: Person Frequency Distribution Curve - English Average.. ....                  | 130 |
| Figure 5.2.5: Person Frequency Distribution Curve - Engagement with practical<br>work. .... | 130 |
| Figure 5.2.6: Person Frequency Distribution Curve – Gender.....                             | 130 |
| Figure 5.2.7: Person Frequency Distribution Curve – Attitudes Towards Physics               | 130 |
| Figure 5.2.8: Person Frequency Distribution Curve - Home language .....                     | 130 |
| Figure 5.3: Learning contexts and student outcomes.....                                     | 141 |
| Figure 6.1: Summary of key-findings.....                                                    | 161 |
| Figure 6.2: Conceptual framework in this study. ....                                        | 163 |
| Figure 6.3: Contextual factors contributing to student outcomes.....                        | 164 |

## List of Tables

|                                                                                                                              |     |
|------------------------------------------------------------------------------------------------------------------------------|-----|
| Table 1.1: Trends in Learner Performance (2011 - 2018) .....                                                                 | 4   |
| Table 3.1: Sample selection .....                                                                                            | 40  |
| Table 3.2: Objectives and outcomes of questions in the DIRECT-instrument .....                                               | 43  |
| Table 3.3: Percentage coverage of scientific domains of DIRECT-instrument .....                                              | 44  |
| Table 4.1: Objectives measured for in DIRECT-instrument .....                                                                | 57  |
| Table 4.2: Summary of achievement of all participants .....                                                                  | 58  |
| Table 4.3: Participants' average performance (%) on questions, objectives, and<br>outcomes of the DIRECT-instrument .....    | 60  |
| Table 4.4: Average performance for each of the eleven objectives and four outcomes                                           | 61  |
| Table 4.5: The Fit Residuals and Item Location values per Test-item .....                                                    | 67  |
| Table 4.6: Comparison of the average use of misconceptions in the current study and<br>an international study .....          | 113 |
| Table 4.7: Participants' ability to translate between circuits presented schematically,<br>realistically, and verbally ..... | 115 |
| Table 4.8: SA performance vs USA-Canada students' performance for different<br>outcomes .....                                | 116 |
| Table 5.1: Classification and selection of questions within the biographical<br>questionnaire .....                          | 119 |
| Table 5.2: Admission requirements for different programs .....                                                               | 120 |
| Table 5.3: Typical profile of the average participant enrolled for different programs ...                                    | 124 |
| Table 5.4: Summary of F-values and p-values of all contextual factors .....                                                  | 127 |
| Table 6.1: Methods summary .....                                                                                             | 149 |
| Table 6.2: Summary of objectives and outcomes .....                                                                          | 151 |
| Table 6.3: Illustration of occurring misconceptions in a South African context .....                                         | 154 |

## **List of Annexures**

|            |                                          |
|------------|------------------------------------------|
| ANNEXURE A | Biographical Questionnaire               |
| ANNEXURE B | DIRECT-Instrument                        |
| ANNEXURE C | Curriculum Content: NCS vs CAPS          |
| ANNEXURE D | Illustration of Common Misconceptions    |
| ANNEXURE E | Assessment Framework: Test-items         |
| ANNEXURE F | Assessment Framework: Contextual factors |

# ***CHAPTER 1:***

---

## **INTRODUCTION AND CONTEXTUALISATION OF THE STUDY**

### **1.1 Introduction**

This chapter contextualises the study and puts the need to conduct this study into perspective. The rationale reviewed the reasons for conducting the study to indicate the general importance of the issue under discussion within science education and its potential contribution to the community at large. The study's aims highlight what the study hoped to achieve and the research problem brings to light the reasons why the focus of the study was on *Electricity and electric circuits*. The chapter concludes by stating the research questions and describing the structure of this study.

### **1.2 Background and Problem Statement**

Science, Mathematics, and Technology education (SMTe) has been investigated in South Africa (SA) in recent years as there is concern about the low levels of achievement at school level (Hekkenberg, 2012; Kriek & Grayson, 2009, Reddy, 2006; Zimmerman, 2015). The matric results determine the performances of secondary school learners, which serve as a measure of the quality of education (Muzah, 2011, p.2). Learner performance in subjects like Physical Science is regarded as highly important as there is a great need for science and technology development in SA.

Figures 1.1 and 1.2 represent the performance distribution of SA learners in Physical Science from 2011-2018. These graphs indicate that most learners obtained averages between 30 and 40% for Physical Sciences during these years, while the number of high-scoring learners remained low over the years.

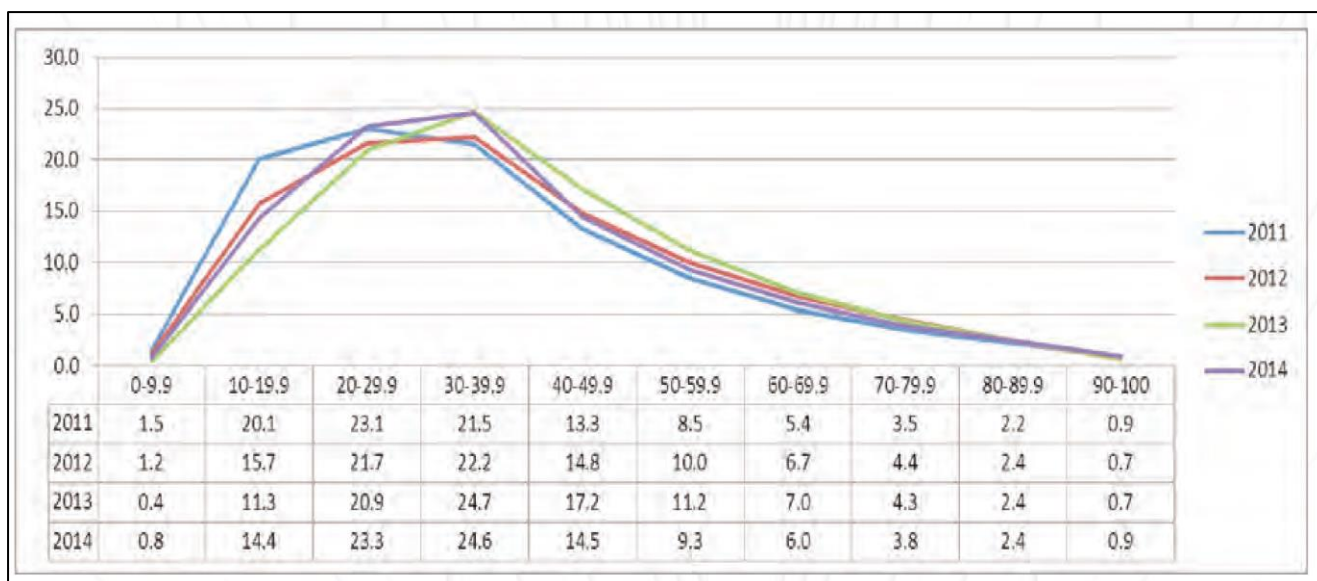


**Figure 1.1: Performance distribution curves 2011 -2014 in Physical Science (DoBE, 2015)**

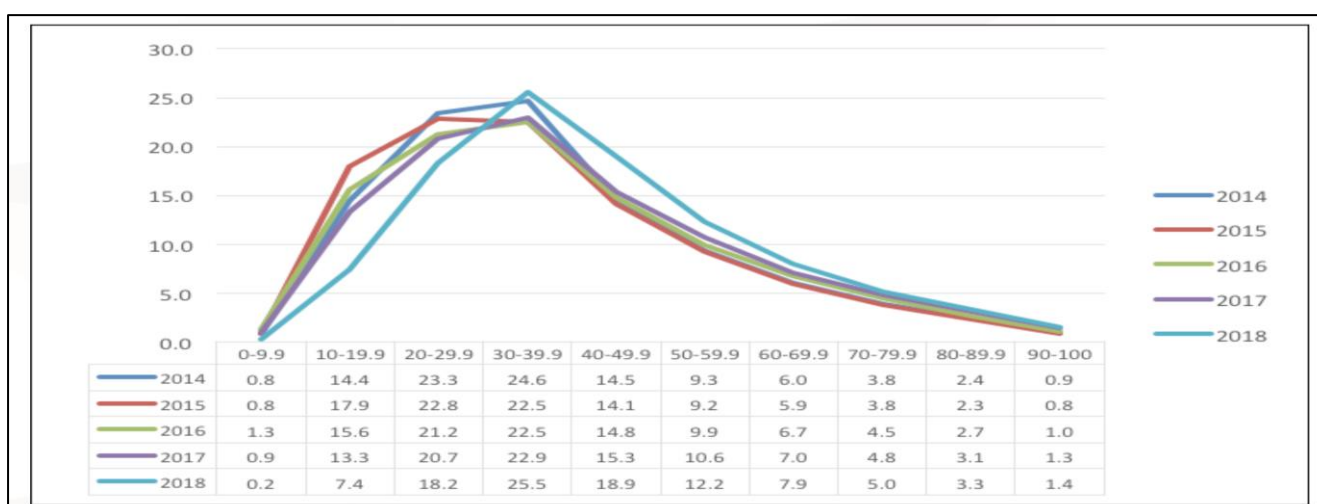


**Figure 1.2: Performance distribution curves 2014 – 2018 in Physical Science (DoBE, 2019)**

It is important to keep in mind that the causes of this problem did not originate only in Grade 12, but were rather built up from lower grades. Physical Science remained problematic over the years in SA, as illustrated by these graphs.

It is clear that remedial measures such as additional classes and winter schools (DoBE, 2020) have been a futile exercise, as the marks continue to be poor. This indicates that the root cause(s) of the poor performance in Physical Science has not been accurately identified as yet.

Mwaba (2011, p.2) indicated that “*school-based factors (the availability and use of teaching/ learning facilities), socio-economic factors (the education of the parents and their economic status), student factors (motivation and attitude), school type, and teachers’ characteristics are factors that contribute to learners’ poor performance in the science subjects.*” The above-mentioned factors have not been addressed sufficiently, as SA is still faced with the same problem of poor conceptual understanding in science.

In the last four decades, various international studies have determined that students’ understanding of scientific concepts does not always comply with scientifically accepted concepts (Driver, 1989). In particular, students’ poor understanding of *Electricity and electric circuits* is well documented internationally (Engelhardt & Beichner, 2004) and locally (Gaigher, 2014). It is generally agreed that students hold misconceptions that are persistent and resistant to change (Driver, 1989). However, this is a matter of ongoing discussion as it has exerted a powerful influence over much of science education research (Sands, 2014). Having a better understanding of students’ current knowledge state would yield useful information to plan constructivist teaching to develop students’ conceptual understanding of electric circuits.

### **1.3 Rationale and Purpose of the Study**

This study is rooted in science education as it explores physics students’ conceptual understanding of simple DC-electric circuits when entering university. In SA, the topic of *Electricity and electric circuits* is presented to learners for the first time in primary school, in the subject natural science. It then continues to the Further Education and Training (FET)-phase as a sub-topic of physics within the subject Physical Science. In the FET-phase *Electricity* is taught predominantly through an algebra-based approach, based on Ohm’s Law, which is introduced when learners reach Grade 11 (DoBE, 2011). Although teaching the topic of *Electricity and electric circuits* requires much conceptual understanding, teachers often choose to teach algebraically, using a procedural approach, neglecting conceptual reasoning (Gunstone et al., 2009; McDermott & Shaffer, 1992). In many cases, teachers do not clearly explain the concepts since they are abstract and teachers want to avoid them. McDermott and

Shaffer (1992) indicated that American students can solve circuit problems algebraically but they are not able to answer simple conceptual questions – a phenomenon that seems to be a universal occurrence. Years later, literature indicates that the problem continues; despite students' capabilities in solving circuit problems algebraically (e.g. when using Ohm's Law). Students find it challenging to develop a good conceptual understanding of electricity and electric circuits (Gunstone et al., 2009; Hart, 2008; Jaakkola et al., 2011).

In improving the effectiveness of secondary education in SA, significant changes in the didactical approach of SA school subjects have been suggested in the past decade (Hekkenberg, 2012). Nevertheless, the latest Trends in International Mathematics and Science Study (TIMSS) that collected achievement data in more than fifty different countries found that SA's scores were the lowest (Letaba, 2017). Student performance cannot be investigated in isolation as contextual factors contribute to the poor results of SA learners in science (Cho, 2010; Howie, 2003, Makgato & Mji, 2006).

Table 1.1 indicates SA learner's performance in Grade 12 Physical Sciences from 2011 to 2018, also showing the performance specifically for electric circuits.

**Table 1.1: Trends in Learner Performance (2011 - 2018)**

| Year                             | 2011  | 2012         | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|----------------------------------|-------|--------------|-------|-------|-------|-------|-------|-------|
| <b>Circuits question average</b> | 31%   | <b>50.9%</b> | 15.5% | 47%   | 41%   | 34%   | 49%   | 39%   |
| <b>Overall average Paper 1</b>   | 53.4% | <b>48.9%</b> | 36%   | 50.1% | 47.6% | 47.4% | 49.3% | 52.9% |

Department of Basic Education (<https://www.education.gov.za/Resources/Reports.aspx>)

Although the Grade 12 learners of 2012 did not achieve the highest overall average for Paper 1 (physics), they achieved the highest average for the question about electric circuits (50.9%). However, the 2012 group should not be regarded as special as the performance in the question relating to electricity, and electric circuits have been consistently lower than the average of the physics paper. It is exactly this issue that supports the interest of this study. Poor conceptual understanding of electric

circuits appears to remain a national problem for many years, and it does not seem likely to change any time soon.

Teachers, as well as learners, often retain a superficial understanding of abstract scientific concepts, as illustrated by the following comment by an experienced biology teacher, teaching physics to secondary school students as part of a basic science module whilst attending a teacher workshop:

*Why does a light globe light up? An easy question, or is it? Sitting in (the) workshop I realized that this was not something I had really thought about. I had just taken it for granted that when you turn on the light switch, the light globe will shine. If I had thought about it in any way, my answer was simple and clear, based on my understanding of year 7 electric circuits. My answer would have been as follows: when you turn on a light switch you complete an electric circuit, thus allowing electricity to flow along the wires and give the light globe the energy to shine. Simple isn't it? But wait, a problem, what is electricity and what 'energy' is it giving to the light globe? (Hart, 2008, p.538).*

Poor conceptual understanding and misconceptions result from the difficulty experienced by learners to comprehend abstract concepts regarding electric circuits. Valid exploration of the understanding of simple DC-electric circuits is therefore highly applicable to both the physics classroom and educational research (Hofer et al., 2017) and would be useful to both secondary school teachers and university lecturers to understand their students' difficulties.

Given the prevalence of misconceptions about simple DC-electric circuits, there is an essential need for a study to explore the conceptual understanding of DC-electric circuits acquired during schooling, particularly for students interested in enrolling for further studies on physics. Such a study may inform teachers and lecturers about their students' conceptual difficulties with electric circuits. Teachers and university lecturers have an academic responsibility to adapt their instructional approaches considering their students' current understanding of electrical theories and models.

Although this study primarily focused on student conceptual understanding of DC-electric circuits and contextual factors relating to their performance, it also concerns

science teaching and the science curriculum. If teachers implement the curriculum with a sound understanding, it should lead to good results, accomplishing the goals of the curriculum. However, in SA, the challenge of poor science performance remains and can be related to a shortage of adequately trained science teachers and socio-economic factors (Cho, 2010; Cho et al., 2014; DoBE, 2019; Du Plessis, 2014; Gaigher et al., 2007; Gaigher, 2014; Makgato & Mji, 2006; Letaba, 2017; Moodley & Gaigher, 2017; Muzah, 2011; Zimmerman, 2015). In particular, teachers' understanding of learners' difficulties in circuits may contribute to the problem (Gaigher, 2014; Moodley & Gaigher, 2017). Although the current study on students entering university physics may reflect on what they learned at school, the issue of teaching electricity at the school level is a challenge beyond the scope of this dissertation.

This study's main focus was to explore the nature of SA students' conceptual understanding of basic circuits. This study's second objective was to explore how students' conceptual understanding of DC-electric circuits relates to contextual factors. The current study focused on first-year university students' results of the DIRECT-instrument in 2013 and some contextual factors to achieve such an aim. The aim can, therefore, be restated as follows:

- Provide clarity about which concepts about electric circuits are not adequately understood by students entering a first-year university Physics module in SA.
- To investigate if there are any significant relationships in first-year university physics students' conceptual understanding of DC-electric circuits and their contextual factors.

The proposed study was based on a secondary analysis of data collected in 2013 from students entering physics at a well-established SA university. These students were mostly from the graduating matric group of 2012.

## **1.4 Research Question**

As discussed in the preceding sections, it seems that the issue of poor conceptual understanding of basic DC-electric circuits is an area in Physical Sciences that

requires further investigation. This can provide important information which can be used to interpret the NSC results, and the outcome of this research will provide a starting point towards the development of more meaningful intervention strategies where needed. The primary research question can therefore, be identified:

#### **1.4.1 Primary research question**

*What is the nature of conceptual understanding about DC-electric circuits amongst students entering first-year Physics at a South African university, and how do their understanding relate to contextual factors?*

The following sub-questions have been pursued throughout this research to ensure that the primary research question will be answered effectively:

#### **1.4.2 Secondary research questions**

- i. How can students' understanding of DC-electric circuits be characterised in terms of critical concepts within the topic?*
- ii. How does a student's conceptual understanding of DC-electric circuits relate to contextual factors?*

A conceptual framework will be introduced in Chapter 2 to investigate those contextual factors and outcomes, which were relevant to the study to answer these two questions effectively. The findings of previous studies based on a school effectiveness model (Cho, 2010; Cho et al., 2014) and the work of Engelhardt and Beichner (2004) on desired outcomes in DC-electric circuits were fundamental in developing such a conceptual framework. The results obtained from the Rasch analysis will be interpreted in terms of this framework. As this current study collected background data in terms of the students, their classroom experience, and their school setting, the data can be used to comprehensively investigate these contextual factors and their significance behind students' conceptual understanding.

Answering the primary research question was accomplished by interpreting the results obtained from the DIRECT-instrument through Rasch analysis, as discussed

in Chapters 4 and 5. To answer the primary research question effectively, it was essential to determine the following:

- Those concepts with regards to DC-electric circuits that SA students understand very well; *and*
- Those concepts with regards to DC-electric circuits that are not adequately understood within SA contexts.

Consequently, the procedures lead to the identification of common misconceptions regarding simple DC-electric circuits amongst first-year university students in SA. Furthermore, students' conceptual understanding may be related to their contextual backgrounds.

Answering these research questions should help understand the nature of the conceptual understanding of simple DC-electric circuits amongst SA students, and if their conceptual understanding can be related to their contextual circumstances.

## **1.5 Potential Benefits of this Study**

It is anticipated that this study will lead to new educational insights about specific challenges that students come across within the topic of *Electricity and electric circuits* that should be addressed in grades 10 – 12 in SA high schools.

Investigating students' different contextual factors enabled the researcher to examine those factors that could possibly contribute towards students' poor conceptual understanding of *electricity and electric circuits*. Thus, the different educational contexts within SA (i.e. type of school students attend – rural school, township school, private school or a city school); the classroom environments students were subjected to (i.e. exposure of practical work) as well as students' personal characteristics (i.e. gender, attitudes towards science, previous performance) are worth examining to explain the difficulties and challenges students experience when studying DC-electric circuits.

It would also be useful to guide future research projects as the results obtained may be utilised to develop and suggest more effective teaching practices. This in turn can be used to promote conceptual change that will substitute students' pre-existing ideas with the corresponding scientifically suitable concepts and perceptions.

As an emerging result of this study, recommendations could also be made to contextualise the DIRECT-instrument to fit within the SA physics curriculum. It may then be used as a baseline or formative assessment in SA classrooms as a tool to examine students' conceptual understanding of simple DC-electric circuits.

## 1.6 Limitations of this Study

This study aimed to explore the nature of first-year university students' conceptual understanding upon entering a SA university. Consequently, the sample was obtained from students that had been admitted into one particular SA University. That implied that all students that participated in this study obtained at least an average of 50% for Physical Science in Grade 12. Students who obtained less than 50% for Physical Sciences in Grade 12 were automatically excluded from the study. As a result, this study does not provide information about lower-performing students.

The university chosen for this study mostly receives students from three of the nine SA provinces. Therefore, this study is not representative of all SA students' conceptual understanding with regards to *Electricity and electric circuits*.

## 1.7 Core Concepts of the Study

### 1.7.1 Conceptual understanding

This refers to the knowing and understanding of more than just isolated facts, but rather the ability to understand a whole system using seemingly isolated facts and transferring this knowledge to new situations; suggesting the capability to relate knowledge in environments other than that in which it was obtained (McDermott, 2001).

### 1.7.2 Misconception

The term misconceptions refer to scientifically incorrect ideas about scientific phenomena. These concepts can be constructed through formal education, informal education, or through students' own life experiences. These preconceptions that conflict with scientific literature are called misconceptions (Driver, 1989; Widodo et al., 2002). Learners often retain misconceptions about a scientific topic after instruction has taken place (Driver, 1989; Moodley & Gaigher, 2017; Shipstone et al., 1988).

### 1.7.3 DC – circuit

A direct current circuit is a circuit where electric current is conducted through the external circuit in only one direction. It is commonly found in many low-voltage applications, especially appliances that can be powered by a battery.

### 1.7.4 Aptitudes

An element that is considered to be the most important factor to influence achievement and is sometimes referred to as prior knowledge (Lindemann-Matthies & Kamer, 2006). Therefore, it refers to the competence to do a certain kind of work at a certain level of independence. Creemers (1994) explains that the ability to understand teaching depends greatly on learner aptitude. Brookhart (1997) established that prior science achievement and general reading capability had the greatest effect on conceptual understanding of scientific concepts in general.

## 1.8 Structure of the Dissertation

This dissertation contains six chapters, as outlined in the following section:

### Chapter 1: Introduction

A general introduction to motivate the work that is presented. This chapter gives a brief overview of the general background and context of the study. This chapter included the title, the objectives, the rationale, the research objectives, and the research questions of the study as well as the location of this study.

## Chapter 2: A literature review

This section is entirely dedicated to the very important topic of *electricity* and its challenges with regards to its learning and teaching. The chapter concluded by introducing a conceptual framework as a strategy used to reflect on learning with regards to the conceptual understanding of basic circuits.

## Chapter 3: Methodology

In this section, a methodology is presented that will support the research objectives of this dissertation. This chapter outlined the participants, describing the sample, instruments, ethical issues, and the study's quality criteria.

## Chapter 4: Results, analysis, and interpretation of test performance

This section gives a detailed description of the findings from the participants' performance on the DIRECT-instrument. Questions from the DIRECT-instrument were used to obtain knowledgeable insights into student's thinking about electrical concepts and how they relate to simple DC-electric circuits. The information gathered was used to answer the first secondary research question.

## Chapter 5: Results, analysis, and interpretation of contextual factors

In this section, the relation of contextual factors to the conceptual understanding of basic DC-electric circuits are explored and discussed. The information gathered was used to answer the second secondary research question.

## Chapter 6: Conclusion

The final chapter of this dissertation discusses the nature of first-year university students' conceptual understanding of simple DC-electric circuits. A thorough discussion of the results is done according to the conceptual framework and the methodology that was used. This is followed by an overview of the sample's contextual factors and their significance to the conceptual understanding of simple DC-electric circuits. Finally, relevant and productive recommendations are made in this chapter, including the recommendations for further research as well as reflecting on the limitations of the study.

# ***CHAPTER 2:***

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## **LITERATURE REVIEW**

### **2.1 Introduction**

A study about students' conceptual understanding regarding simple DC-electric circuits cannot be undertaken without a thorough knowledge of this construct's development in recent research. Most research papers and articles related to the topic of DC-electric circuits indicate a keen interest to (a) pinpoint students' challenges with this topic in Physics, (b) understand why students find this topic challenging, *and* (c) tend to provide suggestions on how to improve student learning with the intent to bring about conceptual understanding. The current chapter aimed to review the approaches, limitations, and conclusions of these interests as they were relevant to this study and establish academic credibility. Many factors influencing student achievement, especially in Science and Mathematics, have been identified in the past decade. By identifying these contextual factors, and those misconceptions that hinder good conceptual understanding, an effective teaching model can be constructed to motivate effective teaching practices.

Chapter 2 has four key parts: The first part reviews current and previous literature related to the conceptual understanding of DC-electric circuits (Sections 2.2, 2.3). The second part reviews various current academic tests used by researchers to determine student conceptual understanding (Section 2.4), while Section 2.5 emphasises those contextual factors that are known to relate to student performance. This chapter concludes with a conceptual framework (Section 2.6) based on the relevant literature and research questions presented in this study.

## 2.2 Electricity and Electrical Circuits

### 2.2.1 General issues that may hinder the effective learning of simple DC-electric circuits.

Research worldwide (Clement & Steinberg, 2002; Engelhardt & Beichner, 2004; Gudula, 2017; Marks, 2012; McDermott & Shaffer, 1992; Moodley & Gaigher, 2017) indicates that there is a keen interest to enrich the quality of both teaching and learning of electric circuits for conceptual understanding. Research has also identified certain learning challenges that learners and teachers often encounter and suggest learning models that can be used to acquire this goal (Marks, 2012). Yet, despite these interests and efforts, it seems that most SA students who have completed their National Senior Certificate (NSC) have not acquired enough breadth and depth about the subject after their instruction to indicate an effective conceptual understanding (DoBE, 2013; DoBE, 2018). Although some conceptual difficulties tend to disappear as instruction progresses, others may persist and interfere with more advanced material learning (McDermott & Schaffer, 1992). McDermott and Schaffer (1992) grouped these learning difficulties according to the following categories:

*(i) Failing to exercise theoretical concepts to an electric circuit.*

Although students can state (recite) definitions for circuit concepts and manipulate algebraic symbols used to represent them, they often cannot relate concepts to one another and or apply them to a real-life circuit.

Research has reported that even if students perform well in quantitative problem solving, they struggle with conceptual questions (Mazur, 1997; McDermott & Shaffer, 1992; Muise, 2015; Von Korff, et al., 2016; Wieman & Perkins, 2005). Some students obtain high scores while lacking a deep conceptual understanding of some basic concepts in physics topics (Hussain et al., 2012; McDermott & Shaffer, 1992). When students are trained to only use mathematical laws and equations to solve numerical problems and taught how to memorise the theory simply to pass an assessment, it has often been observed that the conceptual understanding and recollection of the learned

material is very poor (Fleer, 1994). Teachers are merely teaching their students how to successfully fake understanding (Gaigher et al., 2007).

*(ii) Failing to use and interpret formal representations of an electric circuit.*

According to McDermott and Schaffer (1992), students often tend to manipulate algebraic formulas without relating the correct algebraic symbols to the accompanying concepts. Consequently, they tend to lack a conceptual understanding of diagrammatic representations relating to electric circuits and numerical measurements of electrical quantities. More specifically, students seem to have difficulty understanding that circuit diagrams only represent electrical elements and connections and not any physical or spatial relationships. This is reinforced by the fact that a representation usually bears little resemblance to the actual circuit itself.

The fact that students fail to interpret schematic diagrams may also illustrate another conceptual problem, namely: not treating meters as circuit elements. As a result, they fail to recognise the implications of their construction(s) and or external connections. In their study, McDermott and Schaffer (1992) noticed that students do not seem to regard the voltmeter and ammeter as electrical instruments that need to be connected in a circuit, believing that they do not affect the current or potential difference to be measured.

*(iii) Failing to reason qualitatively about the behaviour of an electric circuit.*

Students often demonstrate local and sequential reasoning rather than to reason globally (Bernhardt & Carstensen, 2015; Engerhardt & Beichner, 2004; Marks, 2012; McDermott & Schaffer, 1992; Moodley & Gaigher, 2017). Students tend to regard an electric circuit as consisting of isolated components, which can be analysed independently from one another.

Sequential reasoning underlies the belief that the direction of the current and order of light bulbs will affect the brightness of the light bulbs in the circuit. When students demonstrate sequential reasoning, they lack the ability to associate the value of the potential difference across the terminals of a light bulb with the brightness of the light bulb. This in turn, may also lead to

inappropriate use of sequential reasoning as students rank the brightness of the light bulbs according to their sequence in the circuit, not considering the potential difference between their terminals (McDermott & Schaffer, 1992).

Another important issue that is often ignored, especially by novice teachers (perhaps due to time constraints in implementing the curriculum), is learner misconceptions. Although literature reveals (Moodley & Gaigher, 2017) that having a sound understanding of learner misconceptions does not automatically guarantee conceptual insights about teaching science in general. It is still recognised when following a constructivist teaching paradigm that knowledge of these misconceptions must be utilised to facilitate conceptual understanding (Bernhardt & Carstensen, 2015; Morrisson & Lederman, 2003).

It is well documented that especially younger learners enter the science classroom with a vast variety of pre-instructional intuitive ideas, heavily influenced by personal experiences, family and or friends, analogies, the media, teachers, and or textbooks (Driver, 1989; Marks, 2012). Both teachers and lecturers have a professional responsibility to familiarise themselves with these known misconceptions and to utilise them to design more meaningful instructional strategies. In doing so, students' current mental models can be reconstructed, which will improve their conceptual understanding. However, it has been noted that even if teachers are conscious of these common misconceptions of their students, it is highly unlikely that they will reform their instructional strategies. (Halim & Meerah, 2002, as cited in Moodley & Gaigher, 2017).

### **2.2.2 Why learning about electric circuits may be difficult**

Literature about *electricity and electrical circuits* is vast. There is no doubt that researchers (Bernhardt & Carstensen, 2015; Fleer, 1994; Moodley & Gaigher, 2017) believe that the majority of students find the topic highly complex and challenging. This might be due to the topic's abstract nature. Students might see the different components that constitute an electric circuit but cannot make scientific observations on a micro level, for example, they cannot observe the rate of "flow" of charge inside the conducting wires (Marks, 2012).

Bernhardt and Carstensen (2015) argue that most pre-university students tend to “cluster” certain concepts about electric circuits together, such as voltage, current, power, and energy. This would imply that most students cannot distinguish clearly between these individual concepts. Consequently, this results in the formation of incorrect scientific ideas about simple DC-electric circuits. The literature indicates that misconceptions are quite stable across different languages and cultural backgrounds (Engelhardt & Beichner, 2004; Gaigher, 2014; Mulhall et al., 2001; Shipstone et al., 1988; Zimmerman, 2015). Misconceptions that repeatedly appear in literature, and which is therefore expected to emerge from the data obtained within this study, can be grouped according to the following categories (Also see Annexure D for illustrations and references):

- (i) **Current consumption model**, where students tend to view current as something that can be “used up” as it “goes around” the circuit. They tend to argue that the current “flowing towards” the light bulb is greater than the current “flowing away” from it back to the battery.
- (ii) **Battery as constant current supply**. Students believe that the battery supplies equal amounts of current, regardless of the resistance and the circuit arrangement.
- (iii) **No current – no voltage**.
- (iv) **Voltage is a property of current**.
- (v) **The unipolar model**, where students tend to believe that only one (1) conducting wire is required between a battery and a light bulb to produce a current.
- (vi) **The clashing currents model**, where students believe that the current would “flow” from both terminals of the battery and “clashes” in the light bulb. Consequently, this would cause the bulb to light up.
- (vii) Research has also indicated that students find it challenging to reason about a circuit as a complete system. They do not understand that local changes within a circuit will result in global changes, affecting both the current through and potential difference across components within a circuit, which has been described as the following two misconceptions:

- (a) **Local reasoning**, where students tend to concentrate their attention only on one aspect in a circuit. A single alteration within the external circuit is commonly thought of as only affecting the current or the potential difference in the circuit where the change has occurred.
- (b) **Sequential reasoning**, where a single change within the external circuit is commonly thought of as only affecting the current or potential difference in circuit devices after the point where the change was made.

An illustration of these misconceptions and a few other less dominant misconceptions can be viewed in Annexure D.

In addition to the many research articles addressing primary school, high school, and university student's misconceptions, a survey by Khumalo and Naidoo (1996) showed that *electricity* proved to be one of the most difficult topics for teachers in KwaZulu-Natal to teach and to explain, especially when teaching Grade 12 learners. Similar results were published by Shipstone (1985). Mahapatra (2006) also established that Indian high school teachers with master's degrees in Physics and with histories of long teaching experiences held alternative conceptual frameworks on different aspects of electric circuits. Some of the most common mental models like the *current consumption model*, the *constant current-source model*, and the *universal applicability of Ohm's law* were the most dominant in these teachers' minds (Mahapatra, 2006). Although important, *Electricity and electric circuits* remain a very difficult topic to teach (Gunstone et al., 2009).

### 2.2.3 Conceptual concerns when teaching and learning electric circuits

The majority of concepts involved in teaching electric circuits (power, energy, potential difference, current, resistance) are predominantly challenging and difficult. They are highly abstract and theoretical and require several wide-ranging analogies (Zimmerman, 2015).

The topic of *Electricity and electric circuits* has a multitude of informal teaching models and analogies, which can help shape students' conceptual understanding regarding the topic. Representations in teaching electric circuits may include analogies, diagrams, stories, online simulations, and practical experiments, to name a few. The problem, however, is that there is often not much agreement about which analogy would be most effective (Zimmerman, 2015), for example, explaining the flow of current by using water as an analogy. Dupin and Joshua (1987) viewed this water-analogy as very problematic and potentially a new misconception. However, McDermott and Shafer (1992) later argued that this particular analogy would be an appropriate starting point to explain the flow rate of current (or flow of charge).

These conflicts highlight that the knowledge for teaching is different compared to the content knowledge of Physics. Jaakkola et al. (2011) argued that analogies are most effective when used in conjunction with hands-on experience and some teacher intervention. However, some analogies and representations are highly abstract and do not lend themselves to be good teaching tools. Hart (2008) makes the critical point that analogies, models, and representations are only effective if the symbolic language they represent is clearly understood by both the teacher and the student and if the teacher is aware of where the analogy fails. Not being able to articulate where an analogy is flawed may potentially be the root of many students' misconceptions regarding the teaching of *Electricity and electric circuits* (Hart, 2008).

### **2.3 Conceptual Understanding of Simple DC-Electric Circuits**

As explained in Section 1.7.1 (p. 9), conceptual understanding refers to knowing and understanding more than just isolated facts. Rather, it is the ability to understand a whole system using isolated facts and transferring this knowledge to new situations (McDermott, 2001). This implies that one should have the skill to relate knowledge in circumstances other than that in which it was obtained.

The National Curriculum and Assessment Policy Statement (CAPS) aims for learners to achieve the following when learning Physical Science:

- To ensure that students can obtain and relate knowledge that is meaningful in their everyday life situations.
- To encourage a critical and dynamic methodology to learn, rather than repetitive and uncritical learning of scientific concepts.
- Students should be capable of achieving the minimum standards of knowledge and skills.
- To provide education to SA students that would be equivalent in quality, breadth, and depth compared to other countries (DoBE, 2011, p.3).

Therefore, when students matriculate, the SA curriculum (CAPS) requires students to:

- (i) Solve problems mathematically involving current, voltage, and resistance for circuits containing different arrangements of resistors both in series and parallel.
- (ii) Know that a real battery has internal resistance.
- (iii) Solve circuit problems mathematically where the internal resistance would be considered (DoBE, 2011, p. 95).

The curriculum expectations are clearly mathematical problem-solving. However, successful algebraic problem solving does not guarantee conceptual understanding. (McDermott & Schaffer, 1992). Therefore, this study investigated conceptual understanding. The students in the sample all passed Grade 12, however, that does not mean they understand the concepts.

Although the DIRECT-instrument used in this study does not deal with internal resistance (points *ii* and *iii* above), it focuses on the reasoning behind point (*i*). Point (*i*) has been put very broadly, but in terms of conceptual reasoning abilities, learners should be able to:

- Understand concepts such as potential difference, current, power, and energy and differentiate between them.
- Know that in a series circuit, the current remains the same throughout.
- State Ohm's Law in words as well as mathematically.

- Use Ohm's Law to describe the connection between current and potential difference, i.e. that for a given resistance, the potential difference across the resistor's terminals is directly proportional to the current through the resistor.
- Describe and understand the relationship between current and resistance, i.e.: For any given electromotive force (emf) in the circuit, if the resistance increases, then the current decreases.
- Electrons are conducted microscopically inside the conducting wire from a higher electric potential (negative terminal) through the whole circuit, where it reaches a lower electric potential (positive terminal).
- Understand that current is a measure of the flow of charges over time.
- In conductors, such as wires, electrons are the only charges that move.
- Know that an object's resistance depends on its length, thickness, and type of material.
- Know that for most conductors, resistivity increases with an increase in temperature.
- Know that resistors are electrical components that resist current.
- Know that batteries are electrical devices that supply electrical energy within a DC-electric circuit.
- Know and understand that resistors in series are potential dividers.
- Know that when working with a series circuit, the resistor with the biggest resistance will have the greatest voltage.
- Know that in a parallel circuit, the potential difference across each of the resistors is equal.
- Know that resistors in parallel are current dividers.
- Know that in a parallel circuit, the smallest resistance gets the most current.
- A short is a pathway of zero resistance within a circuit as the current prefers the least resistance path (DoBE, 2011, p.42-45, 88-89; Engelhardt & Beichner, 2004, p.20-22; Turgut et al.,2011, p.1969).

An overview of the knowledge that students are required to have acquired when matriculating is represented in Annexure C.

To ensure that students conceptually understand the above concepts, processes, and relationships, they must be taught to reason qualitatively and quantitatively (Sands, 2014).

## 2.4 Published Tests Determining Conceptual Understanding of DC-Electric Circuits

### 2.4.1 Different types of questionnaires

In the past three decades, several researchers have developed questionnaires to determine and establish the nature of students' understanding regarding electric circuits. Questionnaires can be classified either as being closed-ended, open-ended, or both (Dawson, 2002). Closed-ended questionnaires have a set memorandum and are prepared in advance (Dawson, 2002; Pathak, 2008). Closed-ended questionnaires are conventionally used to save time since they are simple to oversee and manage; answers can be documented promptly. The same questions are asked in the sample and all the questions have to be answered. Despite its success, there are also associated limitations, such as that out-dated questions may be dealt with, and the participants cannot articulate why they think or reason the way they do (Dawson, 2002; Pathak, 2008).

#### 1 Open-ended questionnaires

Many research attempts have been made to uncover the totality of students' conceptual understanding of simple DC-electric circuits. For example, Dupin and Johsua (1987) developed a 44-item questionnaire to investigate DC-electric circuit concepts' progression from Grade 6 up to a fourth-year university physics course. This questionnaire's aim seemed to be realistic as it was used to assess the quality of teaching on these concepts (p. 793). Although this questionnaire included questions about light bulbs, batteries, and schematic diagrams of simple DC-electric circuits, it was flawed because some questions only provided answer options like: *True/False* or *I don't know*, which increases the guessing factor. However, their study's major weakness is that they do not attempt to provide any statistical evidence for validity or reliability of their questionnaire.

Johnstone and Mughol (1978) later developed a 14-item questionnaire used to study students' conceptual understanding of resistance only. The second-year to fifth-year university students in Glasgow completed this test. The greatest shortcoming of this questionnaire however, is that it does not include any other aspects of basic DC-electric circuits - a shortcoming that limits the use of the questionnaire by other researchers.

This has led authors such as Cohen et al. (1983) to develop another 14-item questionnaire containing ten multiple-choice items and four open-ended items. Only 14 students participated in this study and were interviewed after completing the questionnaire to incorporate their conceptual reasoning behind their choices. Test-items were designed to investigate students' conceptual understanding of interactions between variables in electric circuits. The questionnaire was aimed both at high school students and physics teachers. Apart from the fact that no statistical evidence of the questionnaire's reliability and validity was provided the sample and item sizes were too small, increasing the chance of sampling errors (Engelhardt, 1997). Although no university students were included in the study, some circuits were quite intricate, containing combinations of ohmic resistors and light bulbs, which required students to combine multiple variables and conditions simultaneously.

Later, Shipstone et al. (1988) assembled a 13-item test, given to students between the ages 15-17 in five different European countries. The test-items explored students' conceptual understanding of basic electric circuits, intending to identify differences in conceptual understanding across different countries.

Just before the DIRECT-instrument was developed, Sebastià (1993) assembled a 15-item multiple-choice test that contained test-items combined and improved from both Shipstone et al. (1988) and Dupin and Johsua (1987). Although the emphasis was on selected items' usage by students of sequential reasoning and the superposition misconception, the

test's applicability was limited by the small number and focus of the items. Hence, there arose a need for a standardised test that would assess students' conceptual understanding of DC-electric circuits, involving outcomes such as energy, current, voltage, and the physical aspects of electric circuits.

## 2 Multiple choice / True-or-false type of questionnaires

A computerised diagnostic test was introduced by Lea, Thacker, Kim, and Miller (1994) to investigate students' conceptual understanding of electric circuits. The computerised version was found to give similar results when compared to traditional methods.

The study is mentioned, only to demonstrate that there are other useful ways to administer a multiple-choice test, depending on the context. The main disadvantage was the availability of computers and the software needed to run such programs that were not always very cost-effective at the time. However, since then, major advances have been made in this regard, and computerised questionnaires are now considered to be both very cost-effective and time-saving. The advantages are that the results will correlate with standard pencil-and-paper versions, and it is available in a format that simplifies statistical analysis (Engelhardt, 1997).

Although there may be other diagnostic tests that can be used to investigate students' conceptual understanding of simple DC-electric circuits, one needs to take into consideration that:

- (i) They vary in purpose and the age of the learners targeted by these tests.
- (ii) They differ in the number of items presented.
- (iii) The type of questions used differs.
- (iv) Only a few tests outline the objectives to be covered, while others do not.
- (v) Several of these tests do not include a significant sample of participants with varying abilities.

- (vi) The issue of standardisation is also sometimes doubtful as many of the methods have limited evidence of validity and reliability (Cohen et al., 1983; Dupin & Johsua, 1987; Engelhardt, 1997; Engelhardt & Beichner, 2004; Johnstone & Mughol 1978; Lea et al., 1994; Sebastià, 1993; Shipstone et al., 1988).

#### **2.4.2 The DIRECT-instrument as a diagnostic test**

Gronlund (1981) describes a diagnostic test as an assessment tool that considers persistent or regular content difficulties that are usually left unsolved, forming the foundation of learning difficulties. More specifically, these instruments reveal the breach between what students should know and what they actually know.

Understanding students' learning difficulties regarding DC-electric circuits have been widely reported and extensively explored in literature. However, a great educational advance in understanding challenges was accomplished when Engelhardt and Beichner (2004) presented their results, which were collected after developing and using the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT). The DIRECT-instrument includes 29 multiple choice questions, testing concepts ranging from the physical aspects of simple DC-electric circuits to critical concepts about energy, current, potential difference, and knowledge about the effects on the circuits when connecting resistors in series vs a parallel connection. The DIRECT-instrument makes use of distractors that incorporate naïve conceptions derived from everyday experience. In general, the questions asked in the DIRECT-instrument is not associated with any specific instructional methodology. This ensures that the results obtained would be appropriate for the largest possible sample (Engelhardt & Beichner, 2004, p.7).

Ever since its publication, the DIRECT-instrument (Engelhardt, 1997) has been effectively utilised in a large number of studies, raising awareness both of the presence and persistence of naïve conceptions about simple DC-electric circuits in diverse populations, including those of advanced physics students (Holton, 2008; O'Dwyer, 2012; Sangam & Jesiek, 2012; Zimmerman, 2015). In their studies, Kumar (2002); McMillan and Schumacher (2010); Opie (2004) explain that the

DIRECT- instrument is a questionnaire that can be used as an assessment tool for gathering data, consisting of a set of multiple-choice questions which include representations of DC-electric circuits. Researchers (McMillan & Schumacher, 2010; Pathak, 2008) also agree that it collects valid information from the participants.

Upon completion of a unit on direct current electric circuits and a prior unit on electrostatics, students will be able to do the following:

**Physical aspects of dc electric circuits**

- 1) to identify and to explain a short circuit (more current follows the path of lesser resistance)
- 2) to understand the functional two-endedness of circuit elements (elements have two possible points with which to make a connection)
- 3) to identify a complete circuit and to understand the necessity of a complete circuit for current to flow in the steady state (some charges are in motion but their velocities at any location are not changing and there is no accumulation of excess charge anywhere in the circuit)
- 4) to apply the concept of resistance (the hindrance to the flow of charges in a circuit) including that resistance is a property of the object (geometry of object and type of material with which the object is composed) and that in series the resistance increases as more elements are added and in parallel the resistance decreases as more elements are added
- 5) to interpret pictures and diagrams of a variety of circuits including series, parallel, and combinations of the two

**Energy**

- 6) to apply the concept of power (work done per unit time) to a variety of circuits
- 7) to apply a conceptual understanding of conservation of energy including Kirchhoff's loop rule ( $\Sigma V=0$  around a closed loop) and the battery as a source of energy

**Current**

- 8) to understand and to apply conservation of current (conservation of charge in the steady state) to a variety of circuits
- 9) to explain the microscopic aspects of current flow in a circuit through the use of electrostatic terms such as electric field, potential differences, and the interaction of forces on charged particles

**Potential difference (Voltage)**

- 10) to apply the knowledge that the amount of current is influenced by the potential difference maintained by the battery and resistance in the circuit
- 11) to apply the concept of potential difference to a variety of circuits including the knowledge that the potential difference in a series circuit sums while in a parallel circuit it remains the same

**Figure 2.1: Objectives tested for with the aid of the diagnostic instrument (Engelhardt., 1997, p.72)**

#### 2.4.2.1 Validity when generating test-scores

Engelhardt and Beichner (2004) have ensured the validation of the DIRECT-instrument. It is also a very well-known test used to uncover misconceptions and examine students' conceptual understanding of simple DC-electric circuits. It has been frequently used in past research (Zimmerman, 2015).

According to Engelhard (1997):

*Validity is not a quality that can be established by a single measurement. Evidence for validity is accumulated via several measurements. Data establishing the content (Does the test cover the appropriate material?) and construct (Does the test measure electric circuit concepts like current, voltage, etc.?) validity of DIRECT were obtained. The content validity was established via independent panels of experts while the construct validity was established through individual interviews and factor analyses.*  
(p. 54)

A panel of experts were used to establish the content validity of the DIRECT-instrument. They carefully considered the test items along with their objective(s) to assess whether it fits the domain adequately (Engelhardt, 1997). Students were also sampled and interviewed in an attempt to detect any difficulties regarding the wording of the text or diagrams that were used (Engelhardt, 1997).

To further enhance the validity of the DIRECT-instrument, Engelhardt (1997) also performed a factor analysis, which analyses the interrelationships of data (Engelhardt, 1997, p.144). *"In a factor analysis, the correlations between all items are analysed in order to select groups of items that all appear to measure the same idea"* (Huffman & Heller, 1995, p.138).

#### 2.4.2.2 Reliability when generating test-scores

Another key element that helped shape the quality of this study is known as *reliability*, referring "to the extent to which test scores are free of measurement error." (Muijs, 2004, p.84). Data collection instruments will be useful only if they measure what they are intended to measure and if the data obtained from them is meaningful (Creswell, 2012). Reliability is closely related to validity and refers to the extent that consistency of results is obtained – It addresses the question of

whether similar results would be obtained with another, comparable sample population (Neuman, 2000). Therefore, in a quantitative study, such as the current study, reliability should correspond with the data's dependability and consistency, which should replicate itself over time, in similar contexts but with other instruments and other participating groups (Cohen. et al., 2018). Although a large sample size was used, this study does not claim that the same results would be obtained at other SA universities.

The DIRECT-instrument version 1.0 was redesigned to develop DIRECT instrument version 1.1. The new version was developed to improve the reliability of data over time, as the DIRECT-instrument can be used as both a research tool in assessing new curriculum materials or teaching strategies as well as for evaluating students' conceptual views (Engelhardt & Beichner, 2004). As a result, the Kuder-Richardson formula 20 (KR-20) was used to evaluate the reliability of both versions of the DIRECT instrument and it has been deemed a reliable test (Engelhardt & Beichner, 2004).

## **2.5 Contextual Factors Known to Relate to Students' Conceptual Understanding of Scientific Concepts.**

One of the research questions of this dissertation was to explore and understand how students' contextual factors relate to their conceptual understanding of electric circuits. There is a degree of consensus in the literature that certain factors are mediating students' conceptual understanding concerning electric circuits. These factors include:

### *(i) Gender*

Since the early 1970s, there has been much focus on girls' underachievement in science, as previous literature has shown that male tend to outperform females (Erickson & Erickson, 1984; Greenfield, 1997; Halpern. et al, 2007; Lee & Burkman, 1996).

Sencar and Erilymaz (2003) observed significant gender differences regarding practical hands-on activities vs. theoretical paper and pen tasks in their study.

They found that males performed better on practical items relating to electric circuits; however, no significant difference in the theoretical items was noted.

*(ii) Language of instruction*

When considering learner performance on electric circuits, one ought to reflect on the language of instruction. Learners that are being taught in a second language may have an additional problem of interpreting the language of instruction or translating it to their home language. As such, these learners are confronted with the dilemma of conceptualising their answers in their vernacular and then interpreting it into the language of instruction.

This study did not investigate home language directly. However, one can assume that students who have African languages as their home language may be disadvantaged as they usually attend schools teaching in English.

The 2016 Progress in International Reading Literacy Study (PIRLS) was an intercontinental study regarding the reading and writing ability of Grade 4 and Grade 5 learners. In their investigation, Howie et al (2016) published some disturbing results: When compared to the other partaking countries, the SA learners achieved the lowest mean scores. These findings were quite alarming as the problem continues through to the secondary school level of education. As a result, poorly equipped students are entering higher education institutions.

The teacher, being the primary curriculum developer has the duty to communicate the language of science appropriately while not confusing the students by attempting to adjust scientific terms. The vast majority of SA learners speak African languages at home but receive science instruction in English, and it is difficult to communicate scientific terms in African languages. African languages have never been used officially for science instruction in SA. Science is also taught in Afrikaans in some schools in SA however, it's not offered in any of the other official languages like isiZulu and Sepedi (Gudula, 2017). It should be stated that many scientific terms cannot be expressed in African languages (Hlabane, 2014).

This may have the potential to cause the misinterpretation of a word, for instance, the words gas and air are both “umoya” in isiZulu. It would therefore be a challenge to distinguish between the gas and air in isiZulu. This illustration explains that code-switching for second language learners are not always practical and can lead to possible confusion (Hlabane, 2014). This proves that scientific terms should be taught to learners in English to express themselves and study scientific material correctly.

Howie (2003), an authority on teaching and learning Science and Mathematics in SA, for instance, believes that the most important factor for achieving success in these two learning areas is not dependent on one's socio-economic predisposition, but rather their proficiency of the English language. There is certainly some truth that weak language proficiency in English creates a stumbling block for learning and conceptual understanding in other subject areas. The strong and interdependency between school functionality and learners' socio-economic status and language in SA is a priority to be investigated.

### *(iii) Learner attitudes*

Learner attitudes is another important contextual factor to be investigated as it plays a critical role in science learning. In their article, Abudu and Gbadamosi (2014) view learners' attitudes towards science as a significant factor that relates to their performance and ideas about the subject. Osborne et al. (2003) draw attention to the effect of positive attitudes on educational performance. They concluded that only positive attitudes would result in learners thriving in science. They explain this phenomenon in describing that a positive attitude would lead to an interest in the subject. This in turn would lead to commitment, which is highly likely to guarantee a hunger for academic success.

Research has observed that biology, which, in the school curriculum in SA, is called Life Sciences, is an area of learning that seems important to learners. They consider it a worthy subject related to life and to things they can associate with their everyday life contexts. On the other hand, students

perceive Physical Sciences, as opposed to Life Sciences, as an irrelevant subject, dominated by equations and chemicals that they cannot find relevant within their everyday lives (Barros & Elia, 1974; Osborne et al., 2003).

Osborne et al. (2003) and Mart (2013) have highlighted the critical role of a teacher as it has been reported that a teacher with a positive attitude and commitment has the potential to motivate learners towards a positive attitude in respect of this de-contextualised idea of science and the lack of resources. Many schools in SA are challenged to teach science without science laboratories or the necessary science equipment to perform experiments and demonstrations of scientific phenomena. There is a great need for teachers who can appreciate science beyond the curriculum, who are passionate, self-confident and able to guarantee that the learners understand scientific concepts and phenomena (Tsanwani et al., 2014). Research (Abudu & Gbadamosi, 2014; Barros & Elia, 1974) indicates that teachers who cannot adapt their teaching styles according to their physical teaching environment, who do not consider the needs of their students and who do not portray a positive attitude, have negative attitudes towards science, leading to poor science performance.

#### *(iv) Exposure to practical work*

Another contextual factor that was investigated within this study and that relates to student performance in science is that of teaching methods used to teach science, which includes learner's exposure to practical work and the use of electric circuit apparatus.

Makgato and Mji (2006) draw attention to the fact that poor instruction methods negatively influence the performance of learners in science-related subjects. Weak teaching methods may result from believing that "one teaches the way one is taught", especially when dealing with content difficulties (Makgato & Mji, 2006). Muzah (2011) further points out that some teaching methods reduce science teaching to the point where students are being coached for assessments, rather than enhancing the students' ability to explore ideas through practical activities and experience with laboratory

apparatus. He further accentuates that students continue to study science through habitual learning, resulting in the subject being monotonous. Muzah (2011) also describes that teachers have a habit of being passive when teaching and do not stimulate their students in a creative and practical manner.

It has also been reported (Tshiredo, 2013) that a lack of resources affects learning negatively. In under-resourced schools, this may be problematic as some resources cannot be improvised, for example, a voltmeter and or ammeter needed to complete a DC-circuit. However, McDermott and Schaffer (1992) found and concluded that even if students are exposed to physical “hands-on” activities when performing standard circuit experiments, conceptual development will not be guaranteed. When performing experiments, students are predominantly learning laboratory skills, which do not address their individual learning difficulties. Hence, practical work cannot accomplish what direct teaching fails to do.

Other research studies have recommended constructive alternative approaches like problem-based learning strategies, inquiry-based approaches, and interactive engagement methods, including peer instruction with students working in small groups. These instruction methods may enhance the conceptual understanding of DC-electric circuits (Mbonyirivuze et al, 2019). Some interactive engagement (IE) methods have been introduced in the past to bridge the gap between conceptual understanding and problem-solving ability. These methods aim to help students overcome their misconceptions (Crouch & Mazur, 2001; Gok, 2012; Hake, 1998; Li & Singh, 2017). Hake (1998, p.2) explains that IE methods are *“those methods designed at least in part to promote conceptual understanding through the interactive engagement of students in hands on activities which yield immediate feedback through discussion with peers or instructors.”*

Not exposing learners to practical investigations, would result in the curriculum not achieving its educational objective in teaching learners critical thinking

skills (DoBE, 2011). This shortfall may result in students being unable to use the inductive process of observing the natural world and drawing conclusions.

Moodley and Gaigher (2017) also point out that although the curriculum document plans for various examples of investigations that could be done in the classroom with each topic, teachers end up not doing them as these activities hardly count for any marks. Also, the way final assessments are weighed does not allow teachers to utilise the constructivist approach in their teaching methods, as there is an urgency to cover the curriculum content for examination purposes (Ladwig, 2009; Lelliot, 2014).

## 2.6 Conceptual Framework

Mulhall et al. (2011) argue that the concepts involved in the teaching and learning of electric circuits can be problematic to understand as they are highly abstract and very often presented through analogies.

Two foci are emphasised within this study – firstly, the nature of students’ conceptual understanding of electrical circuits and secondly, the possible relation between the students’ conceptual understanding and their contextual factors. The quest for uncovering the nature or the degree of students’ conceptual understanding of electrical circuits also reveals SA students’ misconceptions with regard to simple DC-electric circuits.

The conceptual framework is based on Engelhardt and Beichners’ (2004) critical outcomes for DC-electric circuits, combined with Cho et al.’s (2014) model of the effectiveness of science education in SA. The frame presents contextual factors as contributors to students’ conceptual understanding of circuits, while critical outcomes (such as *energy, current, potential difference*, and the *physical aspects of DC-electric circuits*) are indicators of conceptual understanding

.

The quality of teaching and learning about DC-electric circuits in SA classrooms is examined from a perspective that considers both the physical and psychological

environment surrounding the students. The environment includes those contextual factors that might relate to students' conceptual understanding of simple DC-electric circuits. The school and classroom environments and learners' personal situations and attributes contribute to the effectiveness of learning, as proposed in school effectiveness research (Creemer, 1994, Scheerens, 1990).

The learning climate, consisting of school, classroom, and student factors, is interactive and interrelated, contributing to learning effectiveness. It is generally accepted that teaching practice and teaching conditions influence academic performance. However, contextual factors at the school level (such as location); classroom level (such as the exposure to practical work), and student level (such as home language, gender, attitudes towards science, and previous performance) might be related to the degree of students' conceptual understanding of DC-electric circuits.

Home language can be considered a student factor and a classroom factor. Learners with African home languages are often disadvantaged in the classroom, while English and Afrikaans home language learners are usually taught in their home language, so they are not disadvantaged. Also, school textbooks and other science texts are not generally available in the African languages. Therefore, home language is primarily considered a classroom factor because that is where it matters to understand science.

A representation of the conceptual framework (Figure 2.2) is based on a combination of the model about the effectiveness of science teaching and the critical outcomes related to electricity and electric circuits. These vital concepts involve aspects of current, energy, potential difference, and electric circuits' physical aspects. The contextual data included information at the personal, classroom, and school levels.

Throughout literature, it has been shown that misconceptions regarding DC-electric circuits are universal, resilient to change, and even preserved by teachers, textbooks, and common experience (Duit et al., 2008; Shipstone, 1988). Misconceptions remain constant throughout different cultures, and it does not disappear through generations. (Bernhardt & Carstensen, 2015; Clement &

Steinberg, 2002; Driver, 1989 ; Engelhardt & Beichner, 2004; Gaigher et al., 2007 ; Gaigher, 2014; Gunstone et al., 2009; Hofer et al., 2017; Zimmerman, 2015). Therefore, the use of these four outcomes mentioned within the conceptual framework will be applicable to explore the degree of learner's conceptual understanding for the matric class of 2012, as well as for future generations.

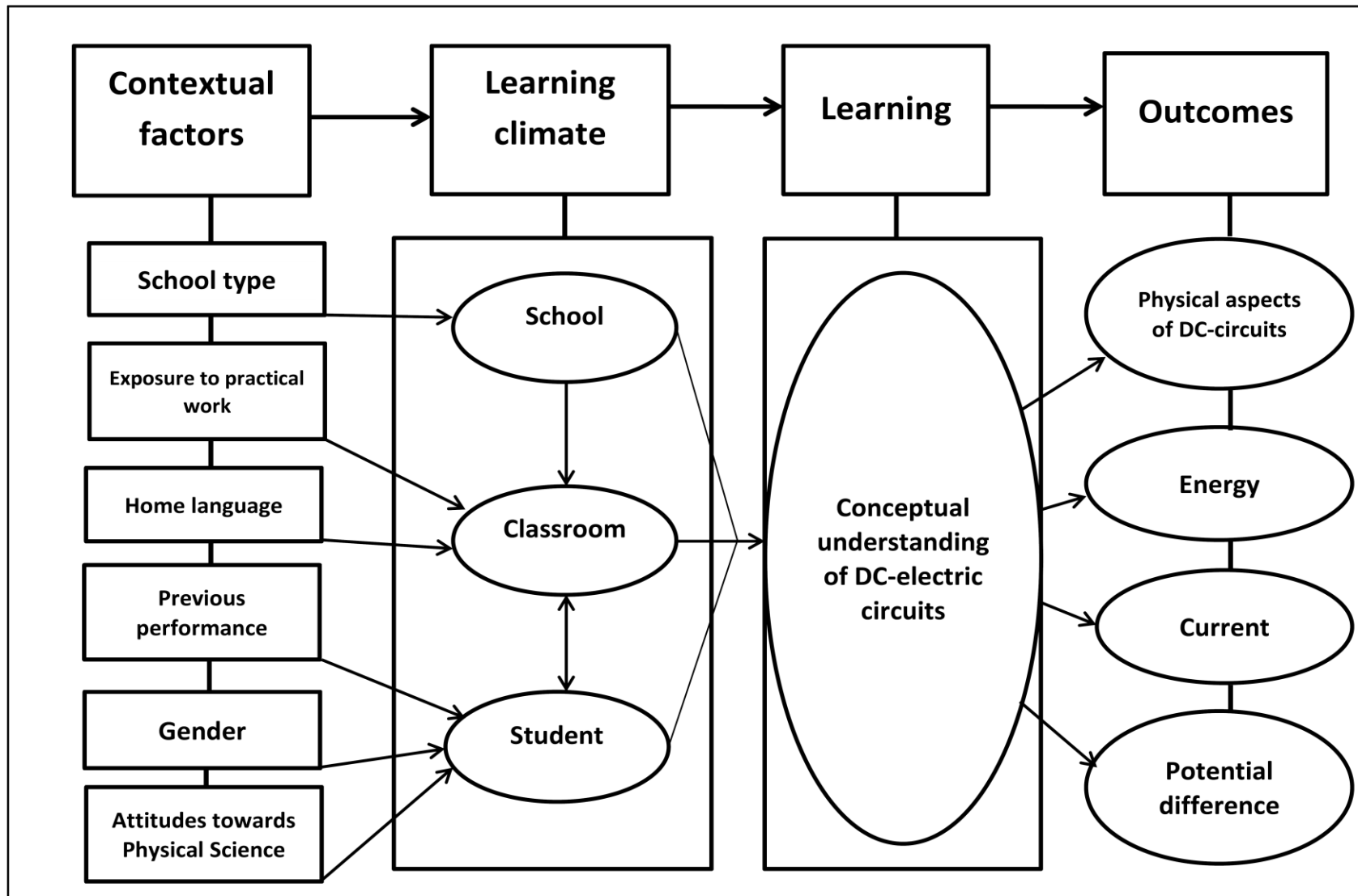


Figure 2.2: Conceptual framework designed to fit with the aim of the study

## 2.7 Conclusion

The topic of electric circuits is conceptually challenging, which requires great skill to teach, which necessitates the investigation of the nature of SA students' conceptual understanding of simple DC-electric circuits and consequently identifying any shortcomings.

Two themes were derived from the research problem, and the literature study was based on these two themes:

1. The nature and or degree of conceptual understanding of DC-electric circuits with regards to SA students; *and*
2. How SA students' conceptual understanding relates to their contextual factors.

Both the nature of the students' conceptual understanding and their contextual factors are of interest to this study. Students' contextual factors might shed some light on how or where these misconceptions manifest.

This literature study provides a starting point for the identification, analysis, and discussion of the nature of participants' conceptual understanding regarding simple DC-electric circuits, providing insights as to why the topic of electric circuits would conceptually be difficult to understand. It seems that further exploration into the low levels of science achievement is called for considering the discussion in previous sections, especially with regards to simple DC-electric circuits. This would provide a basis for creating meaningful intervention strategies. In the next chapter, the methodology for investigating students' nature or degree of conceptual understanding and the strategies used to ensure validity and reliability are described.

# ***CHAPTER 3:***

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## **METHODOLOGY**

### **3.1 Introduction**

This research study's primary objective was to examine the degree of first-year university students' conceptual understanding of DC-electric circuits and to uncover those contextual factors that might relate to their conceptual understanding in a SA setting. This was done by secondary analysis of data that had been collected at a SA university during 2013. For this study to be effective, it required a large sample. Since this study required quantitative methods to examine the data, this study could, therefore, be categorised within a post-positivist paradigm.

This chapter outlines the research design, the method of data collection, the sampling method, the research tools used and the method of data analysis. Thereafter it concludes with the ethical considerations as well as quality criteria.

### **3.2 Research Methodology**

Research conducted within education falls in the domain of social science and primarily consists of two types, namely that of quantitative methods and qualitative methods (Muijs, 2004). Positivists use quantitative data and agree that social science research should be objective, measurable, and free from the researcher's own bias (Zimmerman, 2015). This study's methodology aligned itself with post-positivism as this paradigm acknowledges the limitations of positivism by allowing for subjectivity and interpretation and for the investigation of contextual factors that can consider the complexity of humanity (Cohen et al., 2007). This research did not explore the understanding of how and why students tend to think the way they do, but rather investigated the degree and the nature of their conceptual understanding about simple DC-electric circuits and how this understanding relates to contextual factors.

This research study was based on the secondary analysis of empirical data, produced by objective measurement in the form of a cross-sectional survey design that was not influenced by any personal bias but rather valued precision in analysing the already collected data. Although the last question on the biographical questionnaire involves participants' attitudes, they could only have chosen one of four options as it was a multiple-choice based questionnaire. No room was left for participants to write down and voice their attitudes and or beliefs about the subject of Physical Science. Values and biases were eliminated through the use of objective statistical techniques. In summary, Figure 3.1 illustrates the alignment between the methodological perspectives, methodological frameworks, and research questions.

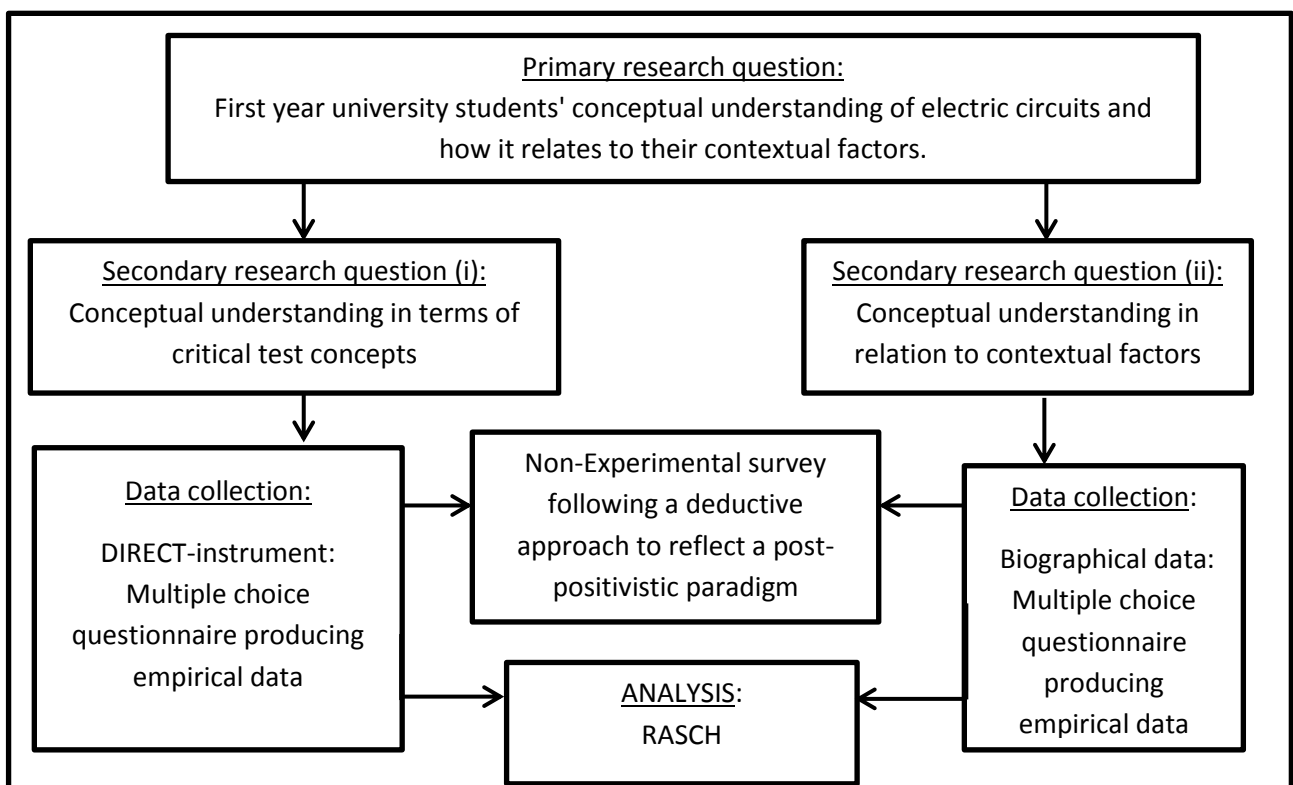


**Figure 3.1: Alignment between research questions, methodology, and instruments**

This research study was based on the analysis of secondary data for a cross-sectional survey that was completed in 2013 to investigate first-year students' conceptual understanding of simple DC-electric circuits. As such, the researcher was not involved during the actual collection of the data. This study benefitted from using secondary survey data as it was both practical and suitable within the aim of this study.

The conclusions of this study (Chapter 6) does not necessarily apply nationwide in SA. However, the finding of this research study represented this reality of the studied topic as best as possible, acknowledging that the researcher's objectivity has helped to establish the nature of first-year university students' conceptual understanding of DC-electric circuits (Muijs, 2004) and how their understanding relates to contextual factors.

### **3.3 Research Design**

Muijs (2004) distinguishes between two types of quantitative research design methods, namely that of experimental-designs and that of non-experimental designs. For this study, a non-experimental survey research design was followed using secondary data. Non-experimental research can be divided into six categories: descriptive, comparative, correlational, survey, ex post facto, and secondary data-analysis (McMillan & Schumacher, 2010).

Cross-sectional survey research is described as a scientific method that gathers data from a large population for purposes of description, exploration, and explanation (McMillan & Schumacher, 2010; Livingstone, 2005). This proposed method considers both the research questions as well as the objectives of this study, since they address the same issues. The sample of students was required to complete the survey, designed as a multiple-choice test (Annexure B) on subject content and a biographical multiple-choice questionnaire (Annexure A). Since no intervention took place before or afterwards, no pre-and post-test was administered.

According to Setia (2016), a cross-sectional research methodology follows an observational study design, where the investigator does not alter the exposure status. The purpose of this cross-sectional study was to collect data to make certain inferences about the population and samples within the population at a certain point in time (Setia, 2016). Figure 3.2 (p.41) illustrates the participants and researcher's different roles within this quantitative cross-sectional research design.

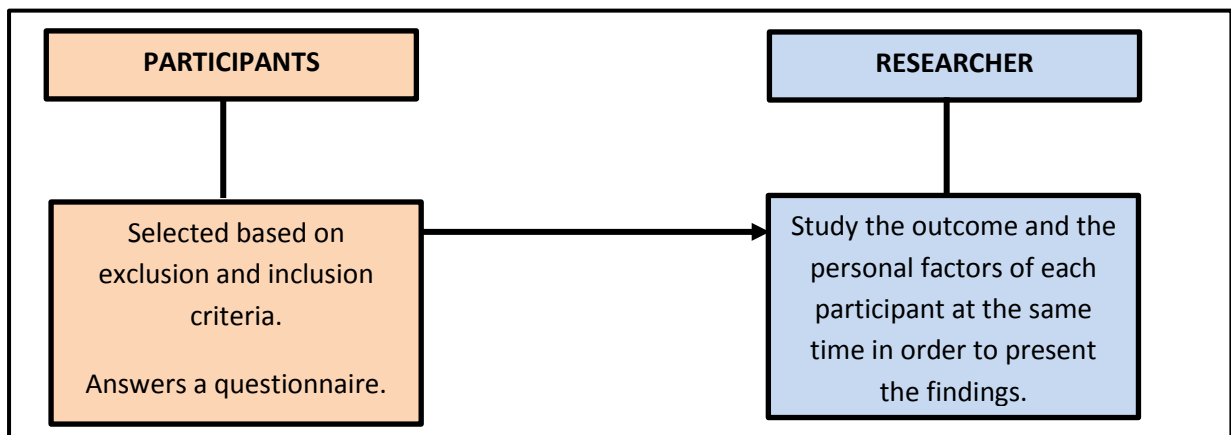


Figure 3.2: Roles and steps involved within a cross-sectional quantitative research design

### 3.4 Sample Selection

The sample of participating students was selected on the grounds of convenience, as they enrolled for any of the four first-year physics modules offered at a SA university that was selected conveniently. The sample consisted of 815 first-year students enrolled within the Faculty of Natural Sciences; Faculty of Engineering, as well as the Faculty of Health Sciences. The sample was subdivided into seven groups, as determined by the different physics modules and language groups for which they have enrolled. Table 3.1 provides the exact number of participants within each group.

Table 3.1: Sample selection

| FACULTY                    | QUALIFICATION                 | * MODULE | NUMBER OF PARTICIPANTS |
|----------------------------|-------------------------------|----------|------------------------|
| <b>Engineering</b>         | B.Eng                         | ENG A    | 145                    |
|                            |                               | ENG E    | 345                    |
| <b>Natural Sciences</b>    | B.SC<br>(Physical Sciences)   | PHS A    | 42                     |
|                            |                               | PHS E    | 50                     |
| <b>Health Sciences</b>     | B.SC<br>(Biological Sciences) | BIOL A   | 40                     |
|                            |                               | BIOL E   | 102                    |
| <b>Biological Sciences</b> | B.SC<br>(Extended Program)    | EXT E    | 91                     |
| <b>TOTAL PARTICIPANTS</b>  |                               |          | <b>815</b>             |

\* Module codes have been altered to ensure the anonymity of the University used within this study

The highest qualification at the time of this study for all the participants was a National Senior Certificate (NSC) obtained in year 12 of the school career.

Although one might regard the number of participants as oversampling, it was however deliberate as it was thought to identify, within the cohort of students, a broader range of contextual factors possibly related to their level and nature of conceptual understanding of simple DC-electric circuits. Although it was not confirmed at the time data collection took place, this study accepts that this university's location indicates that most students are drawn from four of SA's provinces closest to this university.

### 3.5 The DIRECT-instrument

The DIRECT-instrument (Engelhardt, 1997) was suitable for this study as it covers more topics than other tests and integrates many of the learning difficulties and misconceptions about DC-electric circuits that students often deal with, as indicated in the literature review. It is not limited to assessing only one objective. It is also not associated with any specific curriculum, thus, any student completing the DIRECT-instrument will find some of the questions and illustrations to be familiar. Making use of a diagnostic instrument that does not align itself with a specific school curriculum makes the results more valid and generalisable (Engelhardt, 1997). Like most other tests, the DIRECT-instrument is also a multiple-choice test, making it objective and usable for quantitative studies. It is a well-known international test and the researcher wanted to see performance in this particular test. From the study the researcher could detect problematic items and make recommendations for use in SA.

Although the DIRECT-instrument has been standardised in Engelhardt's original thesis (1997), the DIRECT-instrument remains suitable for this study, because:

- (i) A factor analysis has been performed on it (Engelhardt, 1997; Engelhardt & Beichner, 2004), supporting the validity of the test.
- (ii) It can be easily administered to a large sample of participants, making its results more valid and generalisable and also minimising the effects of sampling errors.

- (iii) It is suitable to use for different age groups from high school learners to university students.

The Direct-instrument was therefore chosen as a diagnostic test within the frame of this study as it is a well-known international test, and the researcher wanted to investigate student performance in this particular test. From the study we could detect problematic items and make recommendations for future use in SA (Chapter 6).

### **3.5.1 Outcomes and objectives of the DIRECT-instrument**

The DIRECT-instrument test items are based on a set of 11 objectives grouped into four outcomes as discussed in Chapter 2. Table 3.2 shows how approximately three test items are combined per objective (Engelhardt, 1997). Table 3.2 also lists the objectives, the outcomes, and a description as to what the questions are expecting the students to understand. This would provide more evidence regarding a student's conceptual understanding of any particular objective.

**Table 3.2: Objectives and outcomes of questions in the DIRECT-instrument**

| Objective | Outcome                            | Questions                       | Meaning                                                                                                                                                                                                             |
|-----------|------------------------------------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 – 5     | 1.Physical aspects                 | 14, 4, 5, 9, 13, 19, 22, 23, 27 | Examines students' ability to reason appropriately about the physical aspects of a DC-electric circuit.                                                                                                             |
| 6 - 7     | 2.Energy                           | 2, 21                           | Series circuits with a change in the resistance. The change increases the resistance of the circuit. Students cannot use the battery as a constant current source or current consumed in answering these questions. |
| 10        | 4.Potential difference             | 25                              |                                                                                                                                                                                                                     |
| 11        | 4.Potential difference vs. current | 26                              |                                                                                                                                                                                                                     |
| 10        | 2.Energy                           | 7                               | Examines students' ability to reason appropriately about batteries in series and parallel.                                                                                                                          |
| 6 – 7     | 2.Energy                           | 3, 12                           |                                                                                                                                                                                                                     |
| 9         | 3. Current                         | 11                              | Examines students' understanding of current, its properties, and under what conditions a current will occur.                                                                                                        |
| 1-3       | 1 Physical aspects                 | 10, 18                          |                                                                                                                                                                                                                     |
| 11        | 4.Potential difference             | 24                              |                                                                                                                                                                                                                     |
| 9         | 3. Current                         | 1                               | Deals with how students view the path that charges follow through the circuit.                                                                                                                                      |
| 10        | Potential difference               | 16                              |                                                                                                                                                                                                                     |
| 1         | 1.Physical aspects                 | 19                              |                                                                                                                                                                                                                     |
| 8         | 3.Current                          | 8 ,17                           | Examines students' ability to differentiate between current and voltage.                                                                                                                                            |
| 11        | 4.Potential difference             | 6, 15, 29                       |                                                                                                                                                                                                                     |
| 9         | 3.Current                          | 20                              | Question 20 deals with students' knowledge of how a current is formed while question 28 deals with students' knowledge of an open circuit.                                                                          |
| 11        | 4.Potential difference             | 28                              |                                                                                                                                                                                                                     |

Engelhardt (1997, p.145)

### 3.5.2 Cognitive levels involved in the DIRECT-instrument

The DIRECT-instrument can be used to explore the degree of student's conceptual understanding of simple DC-electric circuits. To do so, it has been designed to explore students' factual knowledge, conceptual understanding, and reasoning skills as shown in Table 3.3.

(i) *Factual knowledge*

It implies knowledge of definite and important scientific facts, information, tools, and procedures. Factual knowledge enables students to participate effectively in doing, understanding, and interpreting science. It is an essential pre-requisite that provides the foundation of their conceptual understanding of concepts.

(ii) *Conceptual understanding*

This involves a student's ability to understand, interpret, and perceive interactions between physical world occurrences and reasoning about abstract scientific concepts from their day-to-day life contexts (Cho, 2010).

(iii) *Reasoning skills*

This relates to students' ability to reason from scientific principles to provide answers when exposed to more complex contexts.

Table 3.3 indicates how the DIRECT-instrument determines the degree of participants' knowledge, skills as well as problem-solving abilities within various content-related contexts (Engelhardt & Beichner, 2004), therefore aligning itself within the aim and conceptual framework of this study. Acknowledgement of these levels of understanding was necessary as more emphasis should be placed on questions that elicit students' analytical, problem-solving, and inquiry skills and capabilities.

**Table 3.3: Percentage coverage of scientific domains of DIRECT- instrument**

| LEVEL OF UNDERSTANDING          | ACTIVITIES                                                                         | PERCENTAGE COVERAGE IN DIRECT-INSTRUMENT |
|---------------------------------|------------------------------------------------------------------------------------|------------------------------------------|
| <b>Factual knowledge</b>        | Recall, recognise                                                                  | 21%                                      |
| <b>Conceptual understanding</b> | Predict, observe, explain, compare, make drawings                                  | 48%                                      |
| <b>Reasoning and analysis</b>   | Analyse, interpret, solve problems, integrate, predict, evaluate, draw conclusions | 31%                                      |

Engelhardt, (1997)

### 3.5.3 Misconceptions revealed by the DIRECT-instrument

Figure 3.3 illustrates how each of the eleven objectives is categorised within the four predominant outcomes assessed within the topic of electric circuits, i.e. *current*, *potential difference*, *energy*, and the *physical aspects* of a DC-electric circuit (Engelhardt, 1997). Within each outcome, it is expected that students may present some misconceptions which can be used to examine the degree of SA students' conceptual understanding of simple DC-electric circuit knowledge.

For example, Question 3 (ANNEXURE A) investigates students' reasoning skills regarding energy conservation and is therefore categorised within the outcome of *energy*. This question can reveal various learner misconceptions; for example, if students selected option *E*, it would indicate the *battery superpositioning misconception*. Should they select option *B*, *battery as a constant current source*, or even *local reasoning* is revealed as a misconception.

Question 8, on the other hand, investigates a student's factual knowledge regarding the outcome of current in a basic DC-electric circuit. Students should already know that the current remains the same throughout a series circuit at the first-year university level. If students selected option *A*, it would reveal the *weakening current misconception*. Similarly, every question within the DIRECT-instrument can be categorised according to a specific outcome, revealing certain misconceptions. Each question will be analysed when discussing results in Chapter 4.

Appendix E provides the assessment framework for each test item, indicating the correct answer and the dominant misconception tested by the question.

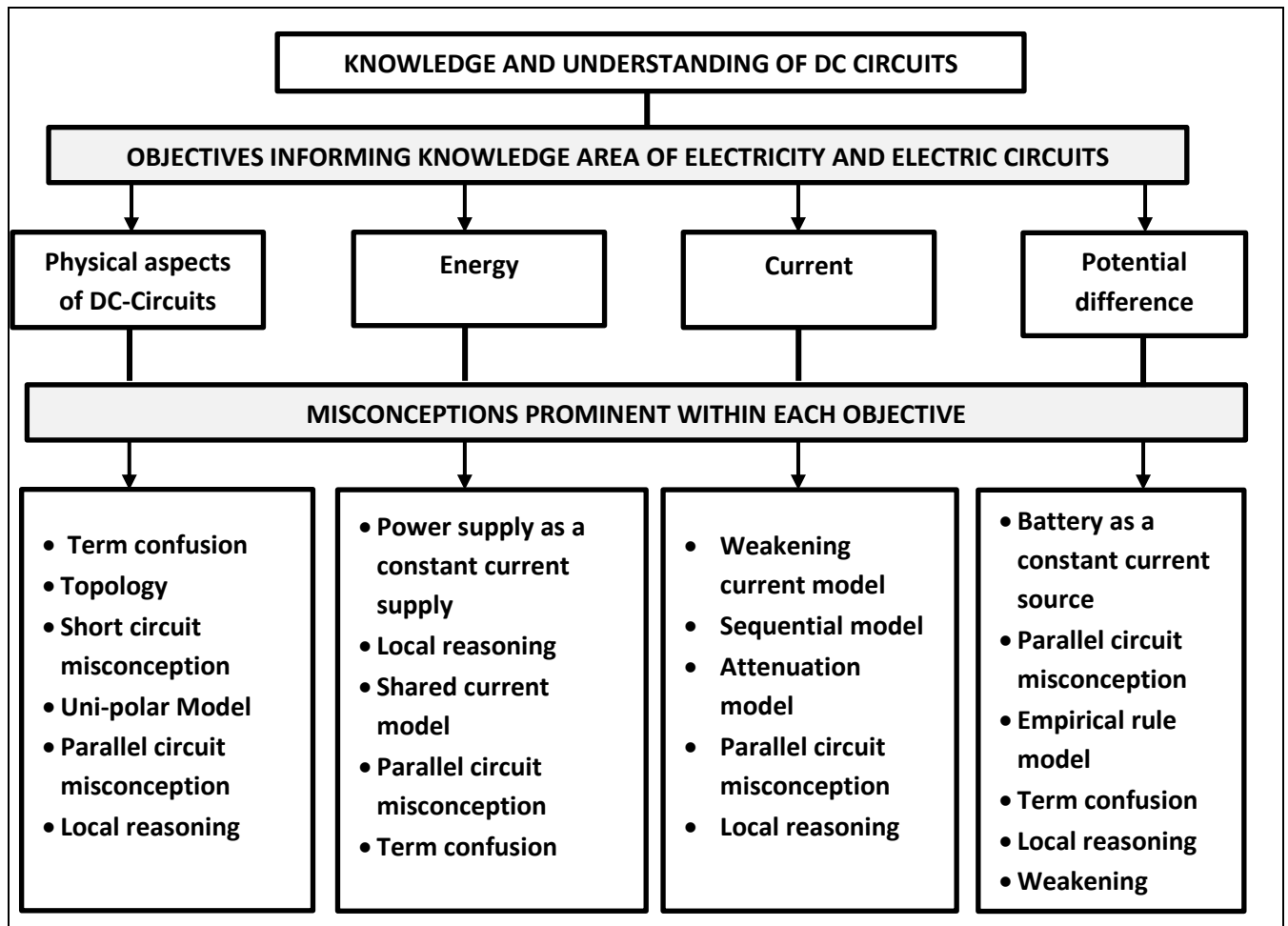


Figure 3.3: Misconceptions associated with the four test objectives

### 3.5.4 The SA curriculum and the DIRECT-instrument

It is noteworthy to mention that a large-scale international assessment like the DIRECT-instrument is not guaranteed to include all the content taught. Some of the content knowledge included in the DIRECT-instrument was not covered in the SA curriculum, such as a circuit at the micro-level or understanding what a short circuit is. Though students should be able to define, understand and identify a short-circuit in a diagrammatic representation, it is a concept that is not always emphasized in the classroom or in textbooks.

### 3.6 The Biographical Questionnaire

The biographical questionnaire consisted of 11 questions (Annexure A) based on factors that may be associated with students' conceptual understanding of simple DC-electric circuits. Participants in this study answered these questions about their

biographical or contextual circumstances. The objective was to collect details about the participants' personal and school contexts. Factors known to be associated with academic performance include: home language (Hlabane, 2014; Setati, 2011), previous performance, gender (Sencar & Erilymaz, 2003), and attitudes towards science (Abudu & Gbadamosi, 2014). This questionnaire was in a multiple-choice format, and its layout can be illustrated in Table 3.4.

Table 3.4 indicates the three learning environments illustrated within the conceptual framework (Chapter 2, p. 35), namely the school environment, the classroom environment, and understanding influenced by factors relating to the student as an individual. All three learning environments contain contextual factors known to influence academic performance, and hence conceptual understanding.

**Table 3.4: Grouping of contextual factors in the biographical questionnaire**

|                                             |                                                                                                        |
|---------------------------------------------|--------------------------------------------------------------------------------------------------------|
| <b>(i) School environment</b>               |                                                                                                        |
| Type of school attended                     |                                                                                                        |
| <b>(ii) Classroom environment</b>           |                                                                                                        |
| Exposure to practical work<br>Home language |                                                                                                        |
| <b>(iii) Student:</b>                       |                                                                                                        |
| <b>Performance</b>                          | Physical Science final school result<br>Mathematics final school result English<br>final school result |
| <b>Characteristics</b>                      | Gender                                                                                                 |
|                                             | Attitudes towards physics                                                                              |

The findings and results on first-year university students' conceptual understanding relating to their contextual factors can be found in Chapter 5.

### 3.7 Data Collection

#### 3.7.1 Data collection

This study commenced the data collection process after distributing the research instrument to 815 consenting first-year university students, enrolled for any one of four different physics modules at the selected university. All of the participants completed the DIRECT-instrument during scheduled lecture time for their physics modules. Although the participants did not all complete the DIRECT-instrument simultaneously, this did not pose a threat to the validity of this research, as there was no pressure on students to obtain high scores by trying to find answers from other groups. It was explained to the students that the test result did not count towards their physics marks, but the Physics department needed the results to understand students' challenges regarding electric circuits.

Upon completing the DIRECT-instrument, their answers were consolidated in an *Excel* spreadsheet, where each student's answers were captured separately. The final score was calculated as a mark out of 29 per student and was then converted to a percentage.

Participants completed the DIRECT-instrument before receiving formal lectures on electric circuits within their different university modules to ensure objectivity. This was done to ensure that the study gathered data about the participants' conceptual understanding of *electric circuits* before tertiary instruction. A large sample size was required to decrease the degree of sampling error (Best, 1981).

### 3.8 Data Analysis – The Rasch Model

Data analysis is a way for the researcher to make sense of the data collected (Zar, 1984). With the help of *Excel* and the program's accompanying mathematical and statistical formulae, a profile of the average student participating in this study was created. After the use of descriptive statistics to find averages for the different sample groups, Rasch analysis was used on the collected data to add to the study's validity and reliability. The Rasch model was named after the Danish mathematician Georg

Rasch (Rasch, 1966). Rasch analysis can be defined as a tool that converts ordinal data into values that can be used for statistical analysis (National Association of Geoscience Teachers [NAGT] , n. d.). The latent trait or the construct to be measured within this study was the aptitude of first-year students regarding DC-electric circuits, therefore assessing their degree or nature of their conceptual understanding. It should also be mentioned that although the measuring instrument (DIRECT-instrument) contains multiple ideas to be tested, the Rasch analysis model only measured one underlying construct, i.e. conceptual understanding. Furthermore, the researcher could study the association between students' contextual factors and the outcomes in this design through Rasch-analysis.

Two versions of the Rasch model are available: the dichotomous and polytomous version. Dichotomous data was used in this research study as the responses to the test items were either right (1) or wrong (0). RUMM 2020 software was used to conduct the Rasch analysis (Andrich et al., 2000). This software made it possible to provide fit statistics in terms of item and person fit residuals (Bansilal, 2014). In other words, it indicates the differences between the sample's actual responses and their expected responses.

A valid and conclusive measure can be produced as Rasch analysis maximises the homogeneity of the trait (i.e. conceptual understanding). The assumptions of the Rasch model that is considered in analysing data includes:

(i) Unidimensionality

According to Gerbing and Anderson (1988) "Unidimensionality is a basic Rasch model assumption. Unidimensionality implies that the scale measures only one construct, allowing the items to be summed together to form a scale with only one dimension" (as cited Uddin and Islam, p. 216 ).

(ii) Local independence

Local independence implies that the test items are not in any way related to one another except through the latent trait being measured (Uddin & Islam, 2019);  
*and*

(iii) Invariability

Invariability implies that a valid test should be repeatable in different contexts while the item difficulty and the person ability estimates remain the same (Baghaei, 2010).

The Rasch model considers the following statistical measures to examine the data and to report statistical significance:

- (i) The use of *Chi-square item-trait interaction* statistics establishes the overall fit of the model against the scale. Uddin and Islam (2019) explain that a non-significant chi-square p-value would indicate that the ranking of the items has a dependable nature across all levels of the underlying trait, i.e. conceptual understanding.
- (ii) *Item-fit statistics* shows to which extent the items fit the Rasch model. This is indicated by item-fit residuals (which is acceptable within a range of  $\pm 2.5$ ) (Bond & Fox, 2007).
- (iii) *Differential Item functioning* evaluates the invariance of items to contextual factors. The Rasch measurement theory is centred around the idea that the scale should work in the same way without being affected by the contextual factor (e.g., gender or attitude) being assessed (Pallant & Tennant, 2007). Differential item functioning (DIF) occurs when two sample groups are displaying the same degree of the construct being measured (i.e. conceptual understanding) but with different responses to a test-item. In this study, different contextual factors (i.e. gender such as males vs. females) were compared against sets of item difficulties. DIF is present when significant differences are obtained in the analysis of variance (ANOVA).
- (iv) Rasch analysis also evaluates the distribution of person locations and item difficulties on the same scale (Marais & Andrich, 2018). A well-designed targeted test-item (not too simple and not too challenging) should have a mean value and a standard deviation (SD) of the person location that falls between 0 and  $\pm 1$  logits. A negative mean value would indicate a lower level of the

construct being measured (i.e. a weaker conceptual understanding), whereas a positive mean value would indicate a higher level of the construct being measured (i.e. a better conceptual understanding).

- (v) In RUMM 2020, evidence for reliability is provided by the *Person Separating Index* (PSI). The PSI is equivalent to Cronbach's alpha, yet instead of making use of raw scores, person estimates in the form of logits are used. For the Cronbach's alpha, a value close to 1 indicates high internal consistency, and a value less than 0.7 indicates model misfit (Uddin & Islam, 2019).

### 3.9 Quality Criteria

This study required the accurate measurement of first-year university student's knowledge of electricity and electric circuits—hence the discussion of validity speaks to the heart of the project. In broad terms, validity can be seen as the degree to which a measurement, or “core”, measures what it was intended to measure (Maree, 2016, p.164). Because this was a quantitative study, the validity and reliability of the term were appropriate in determining first-year university students' conceptual understanding of simple DC-electric circuits and their relation with contextual factors.

#### 3.9.1 Validity

Quantitative measurement implicates the allocation of scores to individuals to represent some characteristic of these individuals. How can one know that these scores truly symbolise this characteristic, especially when it is a construct like conceptual understanding that is being measured? This implies that the researcher had to use suitable tools to gather relevant data, suitable instrumentation, and suitable statistical techniques to analyse the data (Cohen et al., 2007).

The validity of the DIRECT-instrument was established by its developer, Engelhardt (1997), with the details being discussed in Chapter 2.

The validity of the data is supported by the design of the study. There was no pressure on students “cheat” to obtain high scores, as was explained in Section 3.7.1 (p.47).

### **3.9.2 Reliability**

Since this research took the form of a cross-sectional survey design, the researcher measured the outcome and the personal factors prevalent in each population sample, studying their association (Setia, 2016). The use of the Rasch-analysis model assisted the researcher in making use of objective analysis. This improved the quality of this research as objective measurement increased the reliability of the results by ensuring that the researcher and the research object remained independent from one another.

The DIRECT-instrument is both reliable and valid and can be used to (Engelhardt, 1997) gain information about students’ conceptual understanding and reasoning about circuit phenomena via multiple-choice testing.

### **3.10 Ethical Considerations**

Because human participants were involved during the course of this study, it was essential to abide by the research ethics (Opie, 2004; Wallen & Fraenkel, 2011). Therefore, approval for this study was applied for and granted by the Ethics Committee of the university. McMillan and Schumacher (2010) as well as Wallen and Fraenkel (2011) argued that credible research can only be done with the consent of all participants, with the researcher protecting the participants, as well as adhering to the privacy and confidentiality of the participants.

This study was based on secondary data. The students who participated in the original study gave their informed consent. The anonymity of the participants was maintained throughout the data collection process. Their participation in the study did not harm the participants. The diagnostic tool used was a useful teaching tool because the questions were conceptual, designed to explore the nature of first-year university students’ conceptual understanding of simple DC-electric circuits.

Ethical clearance has already been obtained from the university during 2013 and was used for the original study. However, the original study's proceeding was delayed and therefore ethical clearance was sought again during 2018 for this study.

### **3.11 Conclusion**

This section has set out the theories that underpin the research methods used and explained why they were chosen. The sampling method used in the study was also discussed. The chapter further described the data collection instruments and the rationale behind their selection. The researcher also described the methodology used to gather and analyse the data obtained. The chapter clarified how validity and reliability were ensured and explained how the ethical considerations were adhered to during the data collection. The methodology, therefore, ensures valid and reliable results to answer the research questions. In the next three chapters, the researcher will present the results of the DIRECT-instrument (Chapter 4) and students' results related to contextual factors (Chapter 5), along with the analysis of the results and the corresponding conclusions (Chapter 6).

# **CHAPTER 4:**

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## **PERFORMANCE IN THE OBJECTIVES OF THE DIRECT-INSTRUMENT: Results, Analysis, and Interpretation**

### **4.1 Introduction**

Academic research indicates that students' understanding and reasoning regarding simple DC-electric circuits often differ from scientifically accepted explanations. It is a known fact that students' understanding of scientific concepts does not always comply with scientifically accepted ones (Driver, 1989; Engelhardt, 1997; Engelhardt & Beichner, 2004; Gaigher, 2014; Moodley & Gaigher, 2017; Shipstone, 1985). For this reason, there arose a need for a study to explore the conceptual understanding of simple DC-electric circuits during schooling, particularly for students interested in enrolling for further studies in physics. The DIRECT-instrument was used as the diagnostic instrument (Annexure B) to assess first-year university students' conceptual understanding of DC-electric circuits within a SA context. The information provided by this diagnostic instrument offered insights into the conceptual difficulties that SA students experience after completing secondary schooling.

The analysis of the results indicated that students have multiple misconceptions. Students tend to confuse terms and assign properties of current to that of potential difference, resistance, energy, and or power.

This chapter provides insight into what concepts regarding DC-electric circuits students in SA struggle with, as it examines and analyses the results obtained from the diagnostic instrument. This chapter will also examine the discrimination index (how well a particular test-item distinguished between participants obtaining a good score and those who performed poorly on the DIRECT-instrument) and how they performed in the objectives (Annexure E and Table 4.3 p.59) tested by each test-item. The results obtained from each test-item are discussed, and how the findings helped answering the first secondary research question of this research project: *“How can students' understanding of DC-electric circuits be characterised in terms of concepts within the topic?”*

## 4.2 The Diagnostic Instrument

Engelhardt and Beichner (2004) explained that the DIRECT-instrument has been developed to evaluate students' understanding of a variety of concepts within the topic of DC-electric circuits and can be used both for high school and university students.

The DIRECT-instrument has been chosen as the diagnostic instrument as it complies with many of the reasons that make published tests attractive to be used by researchers (Cohen et al., 2018), namely:

- (i) It is an objective test instrument.
- (ii) It has been piloted.
- (iii) It has been standardised and can, therefore, be used over a large population.
- (iv) Its validity and reliability has been established and published (Ateş, 2005; Engelhardt & Beichner, 2004; Rosenthal & Henderson, 2006; Ross & Venugopal, 2005).
- (v) It is a parametric test, making statistical calculations possible.
- (vi) It also saves the researcher a significant amount of time in that the researcher does not have to plan, create, pilot, and or refine his or her test instrument.

The following measures were taken to ensure the validity of the data and the reliability of the research project:

- (i) Participants were not informed beforehand that they would be required to complete the DIRECT-instrument during a scheduled lecture period. This was done to reflect their pre-existing understanding and knowledge of DC-electric circuits before formal instruction took place.
- (ii) The completion of the DIRECT-instrument was completely anonymous. It was made clear that the results would only be used for research purposes and thus would not influence the participants' final mark for the physics course they enrolled for.
- (iii) Participants were not allowed to join forces with their peers or ask for assistance from the supervisor while completing the test.

- (iv) Not all participating groups completed the DIRECT-instrument at the same time. All question papers and answer sheets were collected at the end of each session to ensure validity and reliability in this regard. This was done to ensure that the instrument would not be distributed to the other participating groups.

Each of the 29 multiple-choice questions in the DIRECT-instrument can be classified according to four outcomes, as illustrated within the conceptual framework (Chapter 2, Figure 2.1 p.25) and the diagnostic instrument's explanation (Chapter 3, Figure 3.3 p.45). These four outcomes are:

- 1 The physical aspects of DC-electric circuits,
- 2 Current,
- 3 Energy, *and*
- 4 Potential difference.

Each of the above outcomes aims at assessing the nature of participants' perceptions and how it aligns with scientific knowledge. The test instrument can further be divided into eleven objectives, each testing different parts of simple DC-electric circuits. These objectives are presented in Table 4.1 (p.56).

### 4.3 Test Statistics

All 29 test items were multiple-choice items where each correct response was awarded one point. Numerically, each multiple-choice test-item was scored in terms of 1's (ones – indicating a correct answer) or 0's (zeros – indicating a wrong answer) on the *Excel*-spread sheet that was generated. Participants' answers were scored according to the answer key provided by Engelhardt and Beichner (2004). Test-items that were not answered were assigned an X. A candidate's performance in the multiple-choice test indicated the ratio of the correct responses to the number of test-items converted into a percentage score.

**Table 4.1: Objectives measured for in DIRECT-instrument**

| <b>Objective</b>                                                                                                                                                                                                                                                                                                                                                     | <b>Question Number</b> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| <b>Physical Aspects of DC electric circuits (objectives 1-5)</b>                                                                                                                                                                                                                                                                                                     |                        |
| 1) Identify and explain a short circuit (more current follows the path of lesser resistance).                                                                                                                                                                                                                                                                        | 10, 19, 27             |
| 2) Understand the functional two-endedness [xx awkward xx] of circuit elements (elements have two possible points with which to make a connection).                                                                                                                                                                                                                  | 9, 18                  |
| 3) Identify a complete circuit and understand the necessity of a complete circuit for current to flow in the steady state (some charges are in motion but their velocities at any location are not changing and there is no accumulation of excess charge anywhere in the circuit).                                                                                  |                        |
| <b>Objectives 1-3 combined</b>                                                                                                                                                                                                                                                                                                                                       | 27                     |
| 4) Apply the concept of resistance (the hindrance to the flow of charges in a circuit) including that resistance is a property of the object (geometry of object and type of material with which the object is composed) and that in series the resistance increases as more elements are added and in parallel the resistance decreases as more elements are added. | 5, 14, 23              |
| 5) Interpret pictures and diagrams of a variety of circuits including series, parallel, and combinations of the two.                                                                                                                                                                                                                                                 | 4, 13, 22              |
| <b>Circuit layout (objectives 1-3,5)</b>                                                                                                                                                                                                                                                                                                                             |                        |
| <b>Energy (objectives 6-7)</b>                                                                                                                                                                                                                                                                                                                                       |                        |
| 6) Apply the concept of power (work done per unit time) to a variety of circuits.                                                                                                                                                                                                                                                                                    | 2, 12                  |
| 7) Apply a conceptual understanding of conservation of energy including Kirchhoff's loop rule ( $\sum V=0$ around a closed loop) and the battery as a source of energy.                                                                                                                                                                                              | 3, 21                  |
| <b>Current (objectives 8-9)</b>                                                                                                                                                                                                                                                                                                                                      |                        |
| 8) Understand and apply conservation of current (conservation of charge in the steady state) to a variety of circuits.                                                                                                                                                                                                                                               | 8, 17                  |
| 9) Explain the microscopic aspects of current flow in a circuit through the use of electrostatic terms such as electric field, potential differences, and the interaction of forces on charged particles.                                                                                                                                                            | 1, 11, 20              |
| <b>Potential difference (Voltage) (objectives 10-11)</b>                                                                                                                                                                                                                                                                                                             |                        |
| 10) Apply the knowledge that the amount of current is influenced by the potential difference maintained by the battery and resistance in the circuit.                                                                                                                                                                                                                | 7, 16, 25              |
| 11) Apply the concept of pot. diff. to a variety of circuits including the knowledge that the pot. diff. in a series circuit sums while in a parallel circuit it remains the same.                                                                                                                                                                                   | 6, 15, 24, 28, 29      |
| <b>Current and Voltage (objectives 8 and 11)</b>                                                                                                                                                                                                                                                                                                                     | 26                     |

Engelhardt and Beichner (2004. p.100)

Table 4.2 indicates the percentage scores of all the participants in this research study. The average percentage score for the participants in this study was 45,8% with the average score obtained being 12.5 out of a total of 29.

**Table 4.2: Summary of achievement of all participants**

| SYMBOL OF ACHIEVEMENT: PARTICIPATING GROUP |       |        |        |        |        |        |         |             |           |        |        |                   |
|--------------------------------------------|-------|--------|--------|--------|--------|--------|---------|-------------|-----------|--------|--------|-------------------|
| STUDENTS                                   | 1     | 2      | 3      | 4      | 5      | 6      | 7       | TOTAL MARKS | AVERAGE % | MEDIAN | PASS % | AVERAGE MARK [29] |
|                                            | 1-29% | 30-39% | 40-49% | 50-59% | 60-69% | 70-79% | 80-100% |             |           |        |        |                   |
| 815                                        | 98    | 207    | 228    | 143    | 92     | 32     | 15      | 37332       | 45.8      | 44.8   | 34.6   | 12.5              |

Figure 4.1 illustrates the distribution of performance scores of all the participants. This frequency distribution indicates skewness to the left, demonstrating that the majority of students participating in this study found the DIRECT-instrument to be challenging. This is also indicative that the majority of participants had a poor conceptual understanding of DC-electric circuits, resulting in misconceptions. Further investigation will reveal the type and degree of misconceptions.

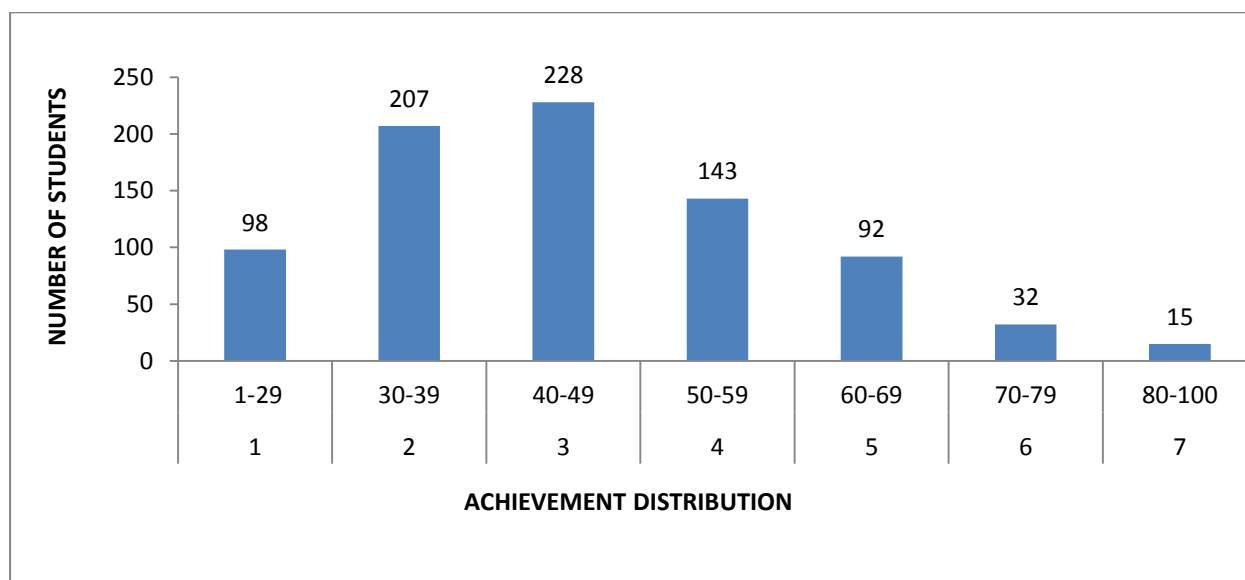


**Figure 4.1: Distribution of participants' performance on the DIRECT-instrument**

The DIRECT-instrument is based on eleven objectives (Table 4.1 p.56). These objectives can be grouped into four outcomes as presented in the conceptual framework of this study (Chapter 2), namely: *the physical aspects of simple DC-electric circuits, energy, current and potential difference (voltage)*. Table 4.3 illustrates how participants performed in each of the instructional objectives provided by Engelhardt and Beichner (2004).

Table 4.3 (p.59) indicates the percentage of correct answers in combination with the linked objective and the outcome.

Upon its examination, Objective 10's questions (dealing with current and potential difference) was the best answered test-items, whereas Objective 9's questions (the microscopic aspects of current) indicated a great need for attention as they were the most challenging to answer. However, when Objective 10 is viewed in combination with Objective 11, then the students did not perform very well (Table 4.4 p. 60). Participants did fine on test-items relating to energy, and the physical aspects of DC-electric circuits.

An investigation, of which distracters were selected, revealed that approximately 49% were unable to locate the contact points on a light bulb, 57% indicated having some confusion regarding current and voltage and 52% could not identify a complete circuit. Another 9% of the participants were unable to identify a short circuit and/or determine what effect the short had on the circuit.

**Table 4.3: Participants' average performance (%) on questions, objectives, and outcomes of the DIRECT-instrument**

| Outcome                         | OBJECTIVE  | QUESTION | OPTION     |            |            |            |            | AVERAGE |
|---------------------------------|------------|----------|------------|------------|------------|------------|------------|---------|
|                                 |            |          | A          | B          | C          | D          | E          |         |
| Physical aspects of DC-circuits | 1          | 10       | 19         | 11         | 434        | 60         | <b>278</b> | 34      |
|                                 |            | 19       | 29         | 138        | <b>493</b> | 63         | 76         | 61      |
|                                 |            | 27       | 137        | <b>405</b> | 146        | 108        | 2          | 50      |
|                                 | 2          | 9        | 184        | 71         | 45         | <b>497</b> | 5          | 62      |
|                                 |            | 18       | 5          | 39         | <b>283</b> | 459        | 8          | 35      |
|                                 | 1, 2 and 3 | 27       | 137        | <b>405</b> | 146        | 108        | 2          | 50      |
|                                 | 4          | 5        | 59         | <b>676</b> | 65         | 0          | 1          | 84      |
|                                 |            | 14       | 242        | <b>424</b> | 131        | 3          | 1          | 53      |
|                                 |            | 23       | 107        | 87         | <b>311</b> | 280        | 4          | 39      |
|                                 | 5          | 4        | 79         | 12         | 348        | <b>260</b> | 94         | 32      |
|                                 |            | 13       | <b>712</b> | 37         | 14         | 19         | 24         | 88      |
|                                 |            | 22       | 23         | <b>183</b> | 140        | 67         | 382        | 23      |
| Energy                          | 6          | 2        | 75         | <b>499</b> | 210        | 3          | 0          | 62      |
|                                 |            | 12       | 275        | 180        | 70         | <b>228</b> | 47         | 34      |
|                                 | 7          | 3        | 29         | 107        | <b>517</b> | 26         | 109        | 64      |
|                                 |            | 21       | 58         | 52         | 183        | <b>390</b> | 114        | 48      |
| Current                         | 8          | 8        | 158        | 63         | <b>579</b> | 2          | 0          | 72      |
|                                 |            | 17       | 35         | 95         | 213        | <b>344</b> | 96         | 43      |
|                                 | 9          | 1        | 262        | 29         | 242        | <b>232</b> | 0          | 29      |
|                                 |            | 11       | <b>191</b> | 130        | 149        | 331        | 1          | 24      |
|                                 |            | 20       | 59         | 66         | 504        | <b>167</b> | 5          | 21      |
| Potential difference            | 10         | 7        | <b>596</b> | 68         | 99         | 3          | 0          | 74      |
|                                 |            | 16       | 126        | 344        | <b>319</b> | 4          | 6          | 40      |
|                                 |            | 25       | <b>556</b> | 33         | 199        | 7          | 3          | 69      |
|                                 | 11         | 6        | 157        | 67         | 69         | 112        | <b>398</b> | 49      |
|                                 |            | 15       | 317        | 131        | <b>346</b> | 3          | 2          | 43      |
|                                 |            | 24       | 475        | 32         | 106        | <b>166</b> | 22         | 21      |
|                                 |            | 28       | 443        | 17         | 82         | <b>246</b> | 4          | 31      |
|                                 |            | 29       | 326        | <b>192</b> | 139        | 82         | 56         | 24      |

\*The number of participants choosing different options are also indicated, and the correct option is highlighted (n=815)

Table 4.4 provides a summary of student performance on the four outcomes as presented in the conceptual framework of this research dissertation. It is recommended to be read in conjunction with Table 4.3 where the performance on each of the 11 objectives is given separately, as well as in combination with other objectives.

**Table 4.4: Average performance for each of the eleven objectives and four outcomes**

| <b>Outcome No</b> | <b>OUTCOMES and Objectives</b>                                                 | <b>Question Numbers</b>                      | <b>Objective Number</b> | <b>Percent Correct</b> |
|-------------------|--------------------------------------------------------------------------------|----------------------------------------------|-------------------------|------------------------|
| <b>1</b>          | <b>Physical aspects of simple DC-circuits</b>                                  | <b>4, 5, 9, 10,13, 14, 18, 19,22, 23, 27</b> | <b>1 - 5</b>            | <b>50,4%</b>           |
|                   | Short circuit                                                                  | 10, 19, 27                                   | 1                       | 48,1%                  |
|                   | Circuit layout                                                                 | 4, 9, 10, 13, 18, 19, 22, 27                 | 1 – 3 and 5             | 47,7%                  |
|                   | Locating contact points on screw-type bulb and complete circuit                | 9, 18                                        | 2 and 3                 | 47,8%                  |
|                   | Short circuit, Locating contact points on screw-type bulb and complete circuit | 27                                           | 1, 2 and 3              | 49,7 %                 |
|                   | Resistance                                                                     | 5, 14, 23                                    | 4                       | 57,7%                  |
|                   | Diagrams                                                                       | 4, 13, 22                                    | 5                       | 47,3%                  |
| <b>2</b>          | <b>Energy</b>                                                                  | <b>2, 3, 12, 21</b>                          | <b>6 - 7</b>            | <b>50,1%</b>           |
|                   | Power                                                                          | 2, 12                                        | 6                       | 44,6%                  |
|                   | Conservation of energy                                                         | 3, 21                                        | 7                       | 55,7%                  |
| <b>3</b>          | <b>Current</b>                                                                 | <b>1, 8, 11, 17, 20</b>                      | <b>8 - 9</b>            | <b>37,1%</b>           |
|                   | Conservation of current                                                        | 8, 17                                        | 8                       | 56,6%                  |
|                   | Micro-macro aspects of DC-circuits                                             | 1, 11, 20                                    | 9                       | 24,1%                  |
| <b>4</b>          | <b>Potential difference (Voltage)</b>                                          | <b>6, 7, 15, 16, 24, 25, 28, 29</b>          | <b>10 - 11</b>          | <b>43,3%</b>           |
|                   | Ohm's Law                                                                      | 7, 16, 25                                    | 10                      | 60,1%                  |
|                   | Potential difference in series vs parallel connections                         | 6, 15, 24, 28, 29                            | 11                      | 33,2%                  |
|                   | Current and Voltage                                                            | 26                                           | 8 and 11                | 41,1%                  |

#### 4.4 Rasch Analysis: Validity and Reliability

Before conducting the Rasch analysis, one first has to establish whether the data fits the model.

Rasch analysis is a psychometric technique that makes use of quantitative methods that allows the researcher to identify and delete misfitting items to improve the validity of the instrument. Although it was not the purpose of this research study to amend the diagnostic instrument, it was necessary to remove some test items post hoc to improve the study's validity for a SA context. The purpose of using the Rasch measurement model was to make valid inferences about the collected data to increase the objectivity of the analysis (Davidowitz & Potgieter, 2016).

One of the first steps in using the Rasch measurement model is to determine and define the construct that will be measured (Bansilal, 2014). In this study, the construct being measured is the conceptual understanding of simple DC-electric circuits. The software automatically converts the raw test scores into a success-to-failure ratio and then to its natural logarithm (Bond & Fox, 2007).

The Rasch model puts the person's ability and the item difficulty on the same scale. This implies that any participant had a 50% chance of choosing a correct response for a test item whose difficulty level is at the same location as a person's ability level. Should it be that a test item's difficulty is above a person's ability, then that participant would have had a less than 50% chance of obtaining a correct response on that specific test-item. Similarly, if an item's difficulty lies below that of the participant's ability, then that participant would have had a greater than 50% chance of choosing the correct answer for that specific test-item (Bansilal, 2014).

The sections that follow describe aspects that were considered when determining the instrument's validity so that inferences about the performance on the test objectives and the biographical questionnaire could be made. Aspects that were considered for validity included the diagnostic instrument itself and aspects to test for fit, including the overall fit, the response dependence, unidimensionality, and differential item functioning (DIF).

#### 4.4.1 Overall fit

##### (i) The Power of Fit:

The Rasch analysis software RUMM 2020 provides item and person statistics that give information about the extent to which the sample and the test fit the model.

The summary statistics are given in Figure 4.2. The Power of Fit indicates a good overall fit for items with an item fit residual of 0.204, a standard deviation (SD) of 2.122, and for persons, a person fit residual of -0.042 and a SD of 0.903. The item location mean is set at zero.

The fit Residual Item Standard Deviation quantifies any deviations from the ideal SD. The ideal SD is 1. A value below 1.4 is considered to be good. The fit residual item standard deviation value (2.122) that had been obtained for this sample was indeed not good and therefore, further discussion is required.

(ii) The  $\chi^2$  Probability Value:

The chi-squared probability ( $\chi^2$ ) value assesses if the ordering of items is consistent across increasing trait levels. The latent trait being tested is that of conceptual understanding of simple DC-electric circuits. This study assumes that if a participant answered a test-item correctly, then they conceptually understand it. However, even a correctly answered question is not a true reflection of conceptual understanding, as this is a shortcoming inherent to any multiple-choice test such as the DIRECT instrument.

The  $\chi^2$  - probability value of 0.00 is less than a significance level of 0.05, which means that the null hypothesis that the sample and the items fit the Rasch model cannot be accepted yet.

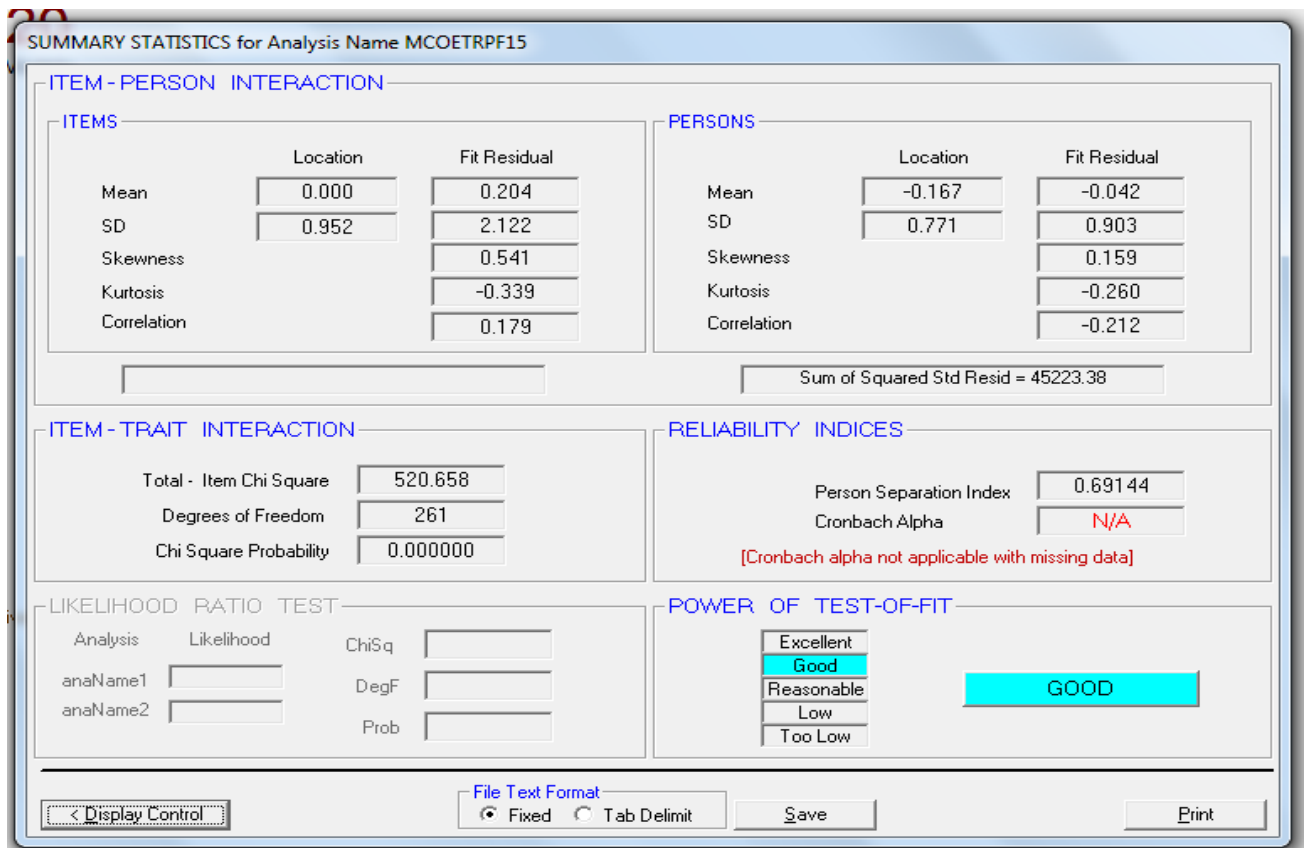


Figure 4.2: Summary statistics for the test and the sample

### (iii) The Mean Item- and Person Fit Residuals

The RUMM 2020 software also provides individual item and person fit residuals. A residual explains the difference between the expected value and the observed value for a particular person or item. In the RUMM 2020 software, these values are highlighted when they fall outside the -2.5 to 2.5 intervals. A value outside this interval will indicate a substantial deviation from the model.

The item (0.204) and person (-0.042) fit residuals (Fig. 4.2) indicate how the observation deviates from the model expectations. A fit residual of zero and an SD of 1.0 would reflect a perfect fit (Salkind, 2006). The fit residuals for items and persons are the first indications of whether or not the data fits the model expectations. Although the summary statistics (Fig.4.2) obtained from the RUMM 2020 software indicated a good power of fit for the test and the model, there remains a misfit between the model and the test as the item and person residuals indicate a deviation from the model expectations. Therefore, the Item fit residuals have been considered and are explained in the sections that follow.

#### (iv) The Individual Item-fit

With individual item fit residuals (Fig 4.3) between -3.617 and 5.079, some items did not fit the sample. The individual item fit residuals in Figure 4.3 indicated that most items behave as expected by the model, except for those test-items that are highlighted, which fall outside the set boundaries. If an item is over-discriminating, the residual will be highly negative (yellow), and if an item is under-discriminating, it will be highly positive (green).

**Figure 4.3: Individual item fit residuals**

| INDIVIDUAL ITEM-FIT for Analysis Name MCREV1PF61 - Serial Order |     |      |      |          |       |          |            |          |     |                                                                                       |        |      |      |          |
|-----------------------------------------------------------------|-----|------|------|----------|-------|----------|------------|----------|-----|---------------------------------------------------------------------------------------|--------|------|------|----------|
|                                                                 | Seq | Item | Type | Location | SE    | FitResid | DF         | ChiSq    | DF  | Prob                                                                                  | F-stat | DF-1 | DF-2 | Prob     |
| 1                                                               | 1   | 01   | Poly | 0.797    | 0.082 | 1.354    | 767.59     | 7.127    | 9   | 0.623906                                                                              | 0.743  | 9    | 786  | 0.669853 |
| 2                                                               | 2   | 02   | Poly | -0.634   | 0.076 | 0.576    | 767.59     | 6.236    | 9   | 0.716075                                                                              | 0.677  | 9    | 786  | 0.730648 |
| 3                                                               | 3   | 03   | Poly | -0.742   | 0.077 | 0.097    | 767.59     | 4.753    | 9   | 0.855293                                                                              | 0.476  | 9    | 786  | 0.891075 |
| 4                                                               | 4   | 04   | Poly | 0.677    | 0.080 | -1.284   | 767.59     | 7.556    | 9   | 0.579474                                                                              | 0.973  | 9    | 786  | 0.461128 |
| 5                                                               | 5   | 05   | Poly | -1.885   | 0.097 | -1.028   | 767.59     | 5.977    | 9   | 0.742199                                                                              | 0.688  | 9    | 786  | 0.720184 |
| 6                                                               | 6   | 06   | Poly | -0.110   | 0.075 | 0.628    | 767.59     | 7.089    | 9   | 0.627898                                                                              | 0.814  | 9    | 786  | 0.603097 |
| 7                                                               | 7   | 07   | Poly | -1.494   | 0.087 | 0.217    | 767.59     | 15.300   | 9   | 0.083008                                                                              | 1.616  | 9    | 786  | 0.106279 |
| 8                                                               | 8   | 08   | Poly | -1.194   | 0.082 | -2.663   | 767.59     | 31.156   | 9   | 0.000278                                                                              | 4.259  | 9    | 786  | 0.000003 |
| 9                                                               | 9   | 09   | Poly | -0.681   | 0.077 | -0.885   | 767.59     | 12.159   | 9   | 0.204476                                                                              | 1.489  | 9    | 786  | 0.147633 |
| 10                                                              | 10  | 10   | Poly | 0.517    | 0.079 | 3.023    | 767.59     | 16.486   | 9   | 0.057398                                                                              | 1.718  | 9    | 786  | 0.081112 |
| 11                                                              | 11  | 11   | Poly | 1.074    | 0.087 | 1.296    | 767.59     | 11.758   | 9   | 0.227291                                                                              | 1.231  | 9    | 786  | 0.272062 |
| 12                                                              | 12  | 12   | Poly | 0.850    | 0.083 | -0.099   | 767.59     | 4.613    | 9   | 0.866655                                                                              | 0.537  | 9    | 786  | 0.848163 |
| 13                                                              | 13  | 13   | Poly | -2.299   | 0.110 | -1.115   | 767.59     | 7.575    | 9   | 0.577480                                                                              | 0.915  | 9    | 786  | 0.511188 |
| 14                                                              | 14  | 14   | Poly | -0.228   | 0.075 | -3.617   | 767.59     | 32.675   | 9   | 0.000152                                                                              | 4.355  | 9    | 786  | 0.000002 |
| 15                                                              | 15  | 15   | Poly | 0.168    | 0.076 | 1.546    | 767.59     | 10.118   | 9   | 0.341046                                                                              | 1.135  | 9    | 786  | 0.334958 |
| 16                                                              | 16  | 16   | Poly | 0.277    | 0.077 | 5.079    | 767.59     | 35.310   | 9   | 0.000053                                                                              | 3.568  | 9    | 786  | 0.000242 |
| 17                                                              | 17  | 17   | Poly | 0.185    | 0.076 | -1.199   | 767.59     | 15.684   | 9   | 0.073778                                                                              | 1.885  | 9    | 786  | 0.051002 |
| 18                                                              | 18  | 18   | Poly | 0.510    | 0.079 | 0.555    | 767.59     | 17.733   | 9   | 0.038406                                                                              | 2.070  | 9    | 786  | 0.029812 |
| 19                                                              | 19  | 19   | Poly | -0.650   | 0.076 | 0.438    | 767.59     | 10.972   | 9   | 0.277642                                                                              | 1.269  | 9    | 786  | 0.249886 |
| 20                                                              | 20  | 20   | Poly | 1.167    | 0.088 | 3.943    | 767.59     | 62.085   | 9   | 0.000000                                                                              | 6.325  | 9    | 786  | 0.000008 |
| 21                                                              | 21  | 21   | Poly | -0.034   | 0.075 | -1.290   | 767.59     | 16.309   | 9   | 0.060704                                                                              | 1.968  | 9    | 786  | 0.040167 |
| 22                                                              | 22  | 22   | Poly | 1.161    | 0.088 | 0.983    | 767.59     | 4.898    | 9   | 0.843123                                                                              | 0.517  | 9    | 786  | 0.863009 |
| 23                                                              | 23  | 23   | Poly | 0.367    | 0.077 | -1.373   | 767.59     | 14.646   | 9   | 0.101131                                                                              | 1.814  | 9    | 786  | 0.062302 |
| 24                                                              | 24  | 24   | Poly | 1.368    | 0.093 | -1.501   | 767.59     | 23.480   | 9   | 0.005206                                                                              | 3.049  | 9    | 786  | 0.001343 |
| 25                                                              | 25  | 25   | Poly | -0.982   | 0.079 | -0.798   | 767.59     | 12.561   | 9   | 0.183507                                                                              | 1.461  | 9    | 786  | 0.158360 |
| 26                                                              | 26  | 26   | Poly | 0.236    | 0.076 | -2.775   | 767.59     | 23.258   | 9   | 0.005642                                                                              | 3.057  | 9    | 786  | 0.001307 |
| 27                                                              | 27  | 27   | Poly | -0.167   | 0.075 | -1.300   | 767.59     | 22.973   | 9   | 0.006259                                                                              | 2.845  | 9    | 786  | 0.002645 |
| 28                                                              | 28  | 28   | Poly | 0.695    | 0.081 | 4.331    | 767.59     | 48.598   | 9   | 0.000000                                                                              | 4.799  | 9    | 786  | 0.000014 |
| 29                                                              | 29  | 29   | Poly | 1.050    | 0.086 | 2.784    | 767.59     | 31.575   | 9   | 0.000236                                                                              | 3.294  | 9    | 786  | 0.000578 |
| Mean                                                            |     |      |      | 0.000    |       | 0.204    | Totals     | 520.658  | 261 | <input checked="" type="checkbox"/> Highlight extrm FitResid values. Set at : +/- 2.5 |        |      |      |          |
| Std Devn                                                        |     |      |      | 0.952    |       | 2.122    | Total Prob | 0.000000 |     | <input type="checkbox"/> Highlight probabilities below the Bonferroni adjustment      |        |      |      |          |

The Item Characteristic Curves (ICC) presented in the following sections were used to discuss these findings in more detail.

Since it was established that the sample and the data fit the Rasch model in the aspects mentioned above, inferences can now be made.

#### 4.4.2 Analysis of items in terms of item location and fit residual

When analysing the effectiveness of a test-item, two statistics are taken into consideration. This included the mean item location values as a measure of the item difficulty and the item fit residuals as a measure of item discrimination.

Item discrimination evaluates how well a test-item separates participants who have mastered the content from students who have not. Individual item fit residuals are a measure of item discrimination (Fig. 4.3 p. 59). The acceptable value for the fit residual ranges between -2.5 and +2.5 as it was set by RUMM 2020. A negative fit residual indicates over discrimination, and a positive fit residual indicates under discrimination. According to Boopathira and Chellamani (2013) “A highly discriminating item indicates that the participants who had high test scores got the item correct, whereas students who had low test scores got the item incorrect” (p. 193).

Participants, who have answered highly discriminating questions correctly, are participants who have done well on the rest of the DIRECT-instrument. Participants who answer highly discriminating questions incorrectly performed below expectation. Negative discrimination (Fig. 4.3 p. 59) of a test-item implies that the question was answered incorrectly – the more negative the value, the more challenging the question. This could possibly indicate a problem with the question, such as bias.

The test-item that indicated the highest level of discrimination was test-item 29 with a fit residual value of 3.442. The test-item that indicated very poor discrimination was test-item 26, with a fit residual value of -2.775. See Table 4.5.

**Table 4.5: The Fit Residuals and Item Location values per Test-item**

| Question Number | OPTION (%) |      |      |      |      | Item Location | Fit Residual Values |
|-----------------|------------|------|------|------|------|---------------|---------------------|
|                 | A          | B    | C    | D    | E    |               |                     |
| 1               | 32.1       | 3.6  | 29.7 | 28.5 | 0.0  | 0.88          | 1.464               |
| 2               | 9.2        | 61.2 | 25.8 | 0.4  | 0.0  | -0.56         | 1.212               |
| 3               | 3.6        | 13.1 | 63.4 | 3.2  | 13.4 | -0.67         | 0.851               |
| 4               | 9.7        | 1.5  | 42.7 | 31.9 | 11.5 | 0.76          | -1.076              |
| 5               | 7.2        | 82.9 | 8.0  | 0.0  | 0.1  | -1.88         | -1.028              |
| 6               | 19.2       | 8.2  | 8.5  | 13.7 | 48.8 | -0.04         | 1.618               |
| 7               | 73.1       | 8.3  | 12.1 | 0.4  | 0.0  | -1.43         | 0.818               |
| 8               | 19.4       | 7.7  | 71.0 | 0.2  | 0.0  | -1.13         | -2.410              |
| 9               | 22.6       | 8.7  | 5.5  | 61.0 | 0.6  | -0.61         | -0.280              |
| 10              | 2.3        | 1.3  | 53.3 | 7.4  | 34.1 | 0.52          | 3.023               |
| 11              | 23.4       | 16.0 | 18.3 | 40.6 | 0.1  | 1.07          | 1.296               |
| 12              | 33.7       | 22.1 | 8.6  | 28.0 | 5.8  | 0.94          | 0.252               |
| 13              | 87.4       | 4.5  | 1.7  | 2.3  | 2.9  | -2.24         | -0.879              |
| 15              | 38.9       | 16.1 | 42.5 | 0.4  | 0.2  | 0.25          | 2.678               |
| 17              | 4.3        | 11.7 | 26.1 | 42.2 | 11.8 | 0.26          | -0.599              |
| 18              | 0.6        | 4.8  | 34.7 | 56.3 | 1.0  | 0.59          | 1.124               |
| 19              | 3.6        | 16.9 | 60.5 | 7.7  | 9.3  | -0.57         | 1.219               |
| 21              | 7.1        | 6.4  | 22.5 | 47.9 | 14.0 | 0.05          | -1.103              |
| 22              | 2.8        | 22.5 | 17.2 | 8.2  | 46.9 | 1.25          | 1.340               |
| 23              | 13.1       | 107  | 38.2 | 34.4 | 0.5  | 0.45          | -1.205              |
| 24              | 58.3       | 3.9  | 13.0 | 20.4 | 2.7  | 1.47          | -1.388              |
| 25              | 68.2       | 4.0  | 24.4 | 0.9  | 0.4  | -0.92         | -0.767              |
| 26              | 38.4       | 7.7  | 6.4  | 41.1 | 4.7  | 0.24          | -2.775              |
| 27              | 16.8       | 50.0 | 17.9 | 13.3 | 0.2  | -0.09         | -0.676              |
| 29              | 40.0       | 23.6 | 17.1 | 10.1 | 6.9  | 1.13          | 3.442               |

#### 4.4.3 Discussion of items excluded from the Rasch analysis.

Questions 14; 16; 20 and 28 had the largest fit residual values in that they deviate significantly from the expected model parameters. For this reason, it was decided that these four test items should be omitted from the data for the DIRECT-instrument to fit within a SA context. To understand this deviation, and why they were omitted, each of these test-items will be examined below and discussed why they do not fit within a SA context.

##### Question 14:

Question 14 in the DIRECT-instrument assesses participants' knowledge about the physical aspects of a DC-electric circuit, especially regarding the total resistance in a series/parallel combination. The objective (Objective 4, Table 4.1) was to establish

whether participants correctly applied the concept of resistance, including that resistance is a property of the object. The outcome tested was the physical aspects of a DC-electric circuit. Fifty-two per cent of the participants answered this question correctly (Table 4.3 p.59). However, 29.6% chose option A, revealing resistive superpositioning as a misconception. Option A was the most popular wrong answer, indicating that almost 30% of the participants reasoned that if more resistors are added in a DC-electric circuit (regardless of the arrangement) the greater the resistance, not understanding that adding resistors in parallel decrease the effective resistance.

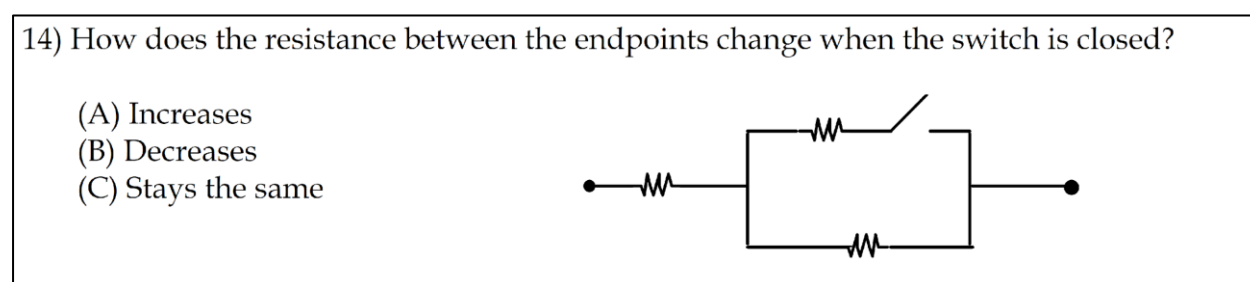


**Figure 4.4: Test-item 14 (Correct option: B)**

Although it seems to be a relatively easy test-item, with 52 % of students answering correctly and item location of -0.228, the large negative Fit residual ( $< -2.5$ ) implies that the item also over-discriminates. This indicates a low level of conceptual understanding of students at the lower end of the ability scale. These students seem to have a problem with objective 4, which is when objectives 1–3 are combined. They seem to have struggled to reason conceptually about circuit diagrams that contain resistors in parallel as well as a series combination. In SA, students are presented with similar diagrams from Grade 10 (Annexure C), so it is surprising that 47% of the participants got this question incorrect. It is possible that the teachers themselves struggled to understand this concept resulting in inadequate teaching. Whatever the reason for the over-discrimination, this item does not fit the Rasch model for the sample.

### Question 16:

Question 16 in the DIRECT-instrument (Fig.4.5) deals with multiple cells and assesses participants' knowledge about the potential difference between parallel cells and parallel resistors. The objective (Objective 10, Table 4.1) of this question is to establish whether participants understood that the amount of current is influenced by the potential difference maintained by the cell and resistance in the circuit (Table 4.1 p.56). The

outcome being tested for was that of potential difference. Thirty-nine per cent of the participants got this question correct, whereas 42% of the participants chose option *B* (Table 4.3 p. 59). The participants that chose option *B* might have reasoned that two cells would result in bulb A in Circuit 2 being brighter compared to bulb A in Circuit 1, therefore indicating having battery superpositioning as a misconception.

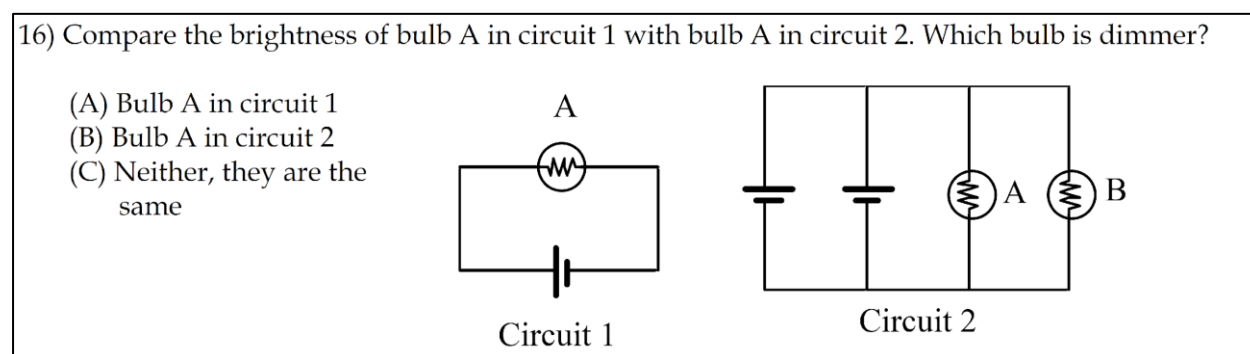


**Figure 4.5: Test-item 16 (Correct option: C)**

This item discriminated poorly, with a fit residual of 5.079, as shown in Table 4.3 (p. 59). This high value indicated that weak students tended to choose the correct answer, while stronger students tended to choose incorrectly. The reason may be weak students combining two misconceptions when thinking about the circuit may end up with the correct answer. Combining the battery superpositioning and resistive superpositioning misconceptions would lead to doubling the voltage and doubling the resistance, resulting in unchanged brightness for each bulb. On the other hand, stronger students having only one of the misconceptions would choose the wrong answer. Whatever the reason for the under-discrimination, this item does not fit the Rasch model for the sample.

### Question 20:

Question 20 in the DIRECT-instrument, tests participants' knowledge of the microscopic aspects of current (Objective 9, Table 4.1 p. 56). The outcome being tested for was that of current. The question assesses participants' knowledge of the electric field inside a bulb filament while it is switched on. The correct answer is that there are charges on the surface of the filament due to the potential difference maintained by the cell. These charges form a gradient that produces an electric field inside the filament.

Only 20% of participants had this question correct, meaning that it was quite difficult. As it also discriminated poorly, shown by the large positive fit residual (3.943), one can

therefore conclude that some low ability students had the item correct, while high ability students had the item wrong. The most popular incorrect choice was C, chosen by 61.8% of the participants (Table 4.3), attributing the cause for the electric field produced in the light bulb's filament to current. The reason for choosing C may be that participants confused cause and effect, choosing the option that current would cause the electric field.

To understand why this test-item does not fit the Rasch model in a SA context, one must consult the National Curriculum Statement (NCS) and the CAPS document (ANNEXURE C). This question's breadth and depth are not covered within the CAPS curriculum and were also not taught to participants under the NCS.

20) Is the electric field zero or non-zero inside the tungsten bulb filament?

- (A) Zero because the filament is a conductor.
- (B) Zero because there is a current flowing.
- (C) Non-zero because the circuit is complete and a current is flowing.
- (D) Non-zero because there are charges on the surface of the filament.

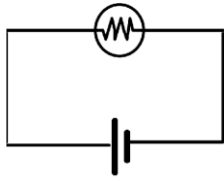


**Figure 4.6: Test-item 20 (Correct option: D)**

### Question 28:

Question 28 deals with participants' conceptual understanding of potential difference across open circuits (Objective 11, Table 4.1 p.56). The outcome being tested for was the potential difference. To get this test-item correct, students had to know that the potential difference across an open circuit equals that across the cell.

The correct option for test-item 28 (Fig. 4.7) was Option D, where 31% of the participants made this selection. However, the majority (54%) of the participants chose Option A (Table 4.3 p.59), revealing that they reasoned that there can be no voltage since there is no current. This way of reasoning reveals confusion between the roles of current and voltage. Students may either believe that the current causes the voltage or they occur simultaneously, indicating that they do not conceptually understand how the elements of a circuit are affected when the circuit is open.

28) What is the potential difference between points A and B?

- (A) 0 V
- (B) 3 V
- (C) 6 V
- (D) 12 V

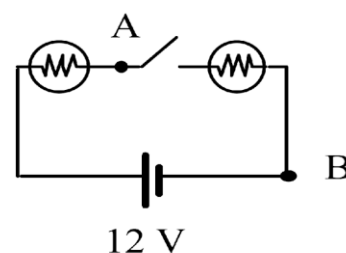


Figure 4.7: Test-item 28 (Correct Option: D)

Students found this question difficult, as only 31% of the answers were correct. Furthermore, the fit residual was large and positive, showing under discrimination. One can, therefore, conclude that it was difficult for students of low and high ability.

Question 28 required students to know that a voltage reading would be possible across an open switch, even with a resistor in place, since the potential difference is the difference in energy per coulomb of charge between the two points. However, Question 28 still does not fit the sample. This might be due to a curriculum problem as the CAPS curriculum (Annexure C) mentions that a circuit must be complete for current to be transferred through it while not exploring potential difference effects. Also, the effect of potential difference in an open circuit is discussed with EMF in Grade 12 but the emphasis is only on calculating internal resistance.

#### 4.4.4 Discussion of the improved overall fit

After the omission of test-items 14, 16, 20, and 28, new summary statistics were obtained, and the new set of results indicated adequate fit to the model. The new summary statistics (Fig. 4.8) indicated a slight elevation of the  $\chi^2$  - probability value from 0.000000 to 0.000001. Although the  $\chi^2$  - probability value did not change much, the mean fit residual value (0.290) of the items now revealed an *SD* value of 1.660, which is much less than the previous value of 2.122. Another factor to consider was the mean fit residual value for persons (-0.057) with an *SD* value of 0.889, suggesting no serious misfit of the respondents within the sample.

Although the data seemed to fit the model, it remained below the acceptable value of 0.05. At this stage of the research study, the researcher was aware of being biased when deleting these test-items to obtain better individual item fit residuals in an attempt to obtain an improved  $\chi^2$  value. For this reason, the deleted test-items were analysed and discussed as it seems that they do not fit for a SA sample.

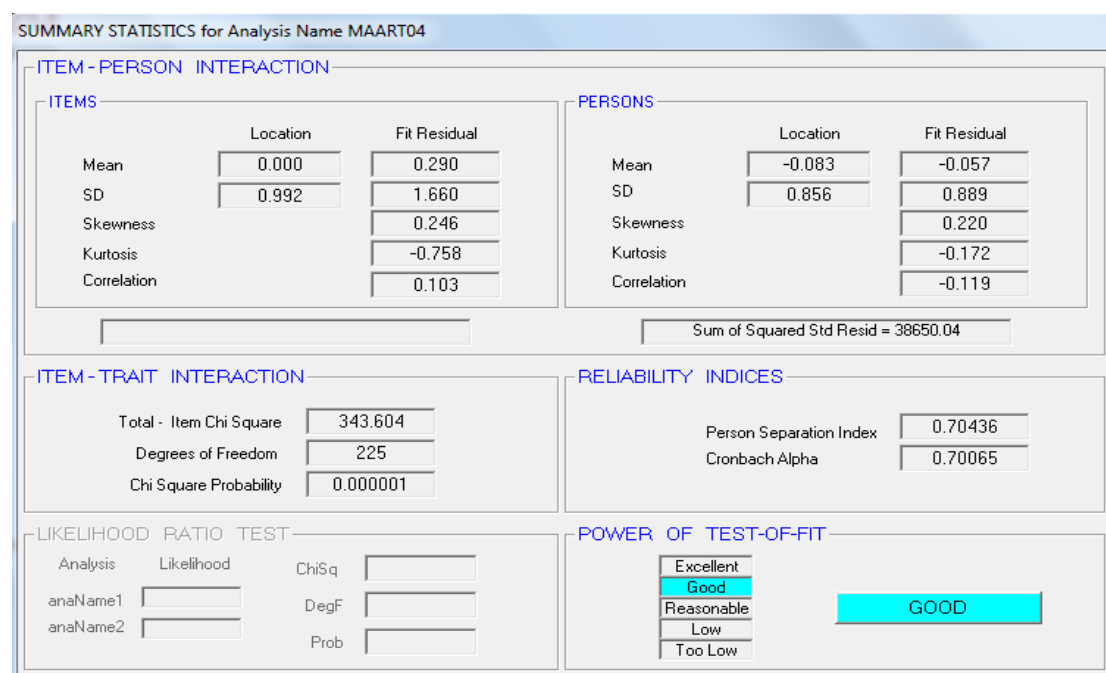


Figure 4.8: Summary statistics after excluding test-items (test-items 14, 16, 20 and 28)

Two additional values that were also considered in conjunction with each other were the PSI (Person Separation Index) value of 0.70436 and the Cronbach  $\alpha$  value of 0.70065. When the persons and items are well aligned, so that there are no extremes, and when there is a complete data set, then the two indices are very close in value, as is the case here. The first set of summary statistics indicated that the Cronbach  $\alpha$  value was not applicable. Therefore, although the  $\chi^2$  probability value is still not desirable, the test of fit remains good, indicating that after excluding items 14, 16, 20, and 28, the data fits the model.

#### 4.4.5 Response dependence

Rasch analysis may indicate high response dependence between two or more test items when they measure the same concept. Should very high response dependence between items be present, one of the items may be considered redundant, and the researcher

may omit one of these items from the measuring instrument. High response dependence can be studied through the residual correlation matrix obtained by the RUMM 2020 software (Figure 4.9). The acceptable level of residual correlation was fixed at 0.3 as set by RUMM 2020. Having such low correlations indicates that each test item is included in the test on its own merit for diagnosing the degree or nature of the participants' conceptual understanding or aptitude with regards to concepts involving simple DC-electric circuits.

At a fixed residual correlation of 0.3, no correlation between any test-items is highlighted, indicating that all test-items have local independence. Having such low correlations indicates a valid analysis for both the test and the sample as it adds to the reliability of the interpretations of the Rasch analysis outcomes, indicating that the researcher was able to proceed with the analysis of the result.

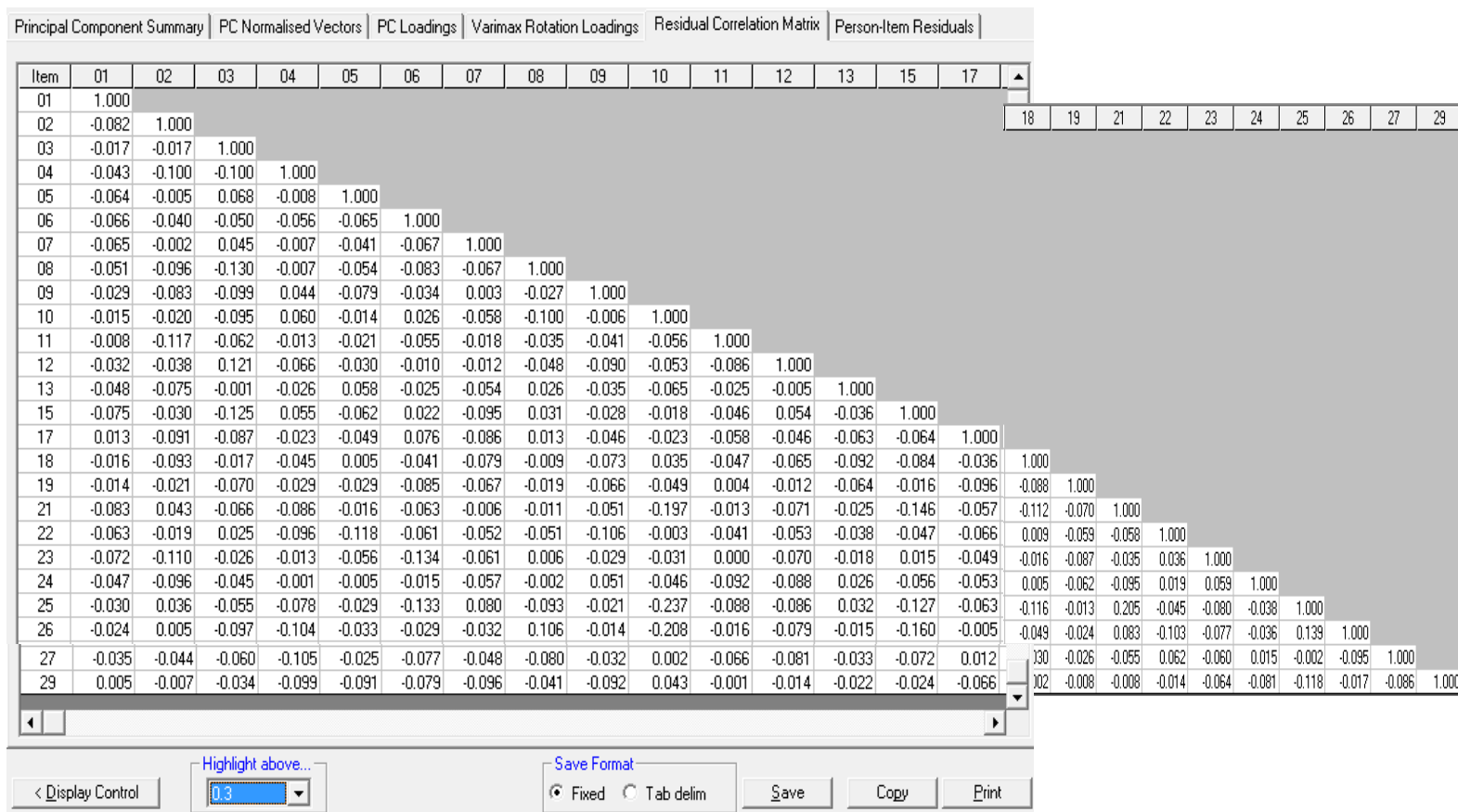


Figure 4.9: Response dependence as calculated through RUMM2020

## 4.5 Discussion of Performance

The test items' relative difficulty concerning participants' abilities is given in the Item map shown in Figure 4.10. Figure 4.10 excludes the non-fitting test-items. An Item map displays the relative difficulty of items against the abilities of participants, as calculated for the dataset. A person with average ability has a 50% chance of getting the item at the 0.00 item location right. Such a person will have a larger than 50% probability to get the items below 0.00 correct. In other words, items below the 0.00 item location would have been experienced as easy by the average participant, whereas those test items above 0.00 would have been experienced more difficult or challenging.

Figure 4.10 shows that test-item 13 was the easiest, while test-item 24 was the most difficult to answer correctly for the sample. Comparing these results to Table 4.3 (p.59) shows that 88% of participants answered question 13 correctly, indicating that it was indeed experienced as an easy item. On the other hand, only 21% of participants answered question 24 correctly. Fifty-seven per cent of the students were below the 0.0 person location. This indicates the majority of students had difficulty displaying a good conceptual understanding of concepts relating to more challenging test-items.

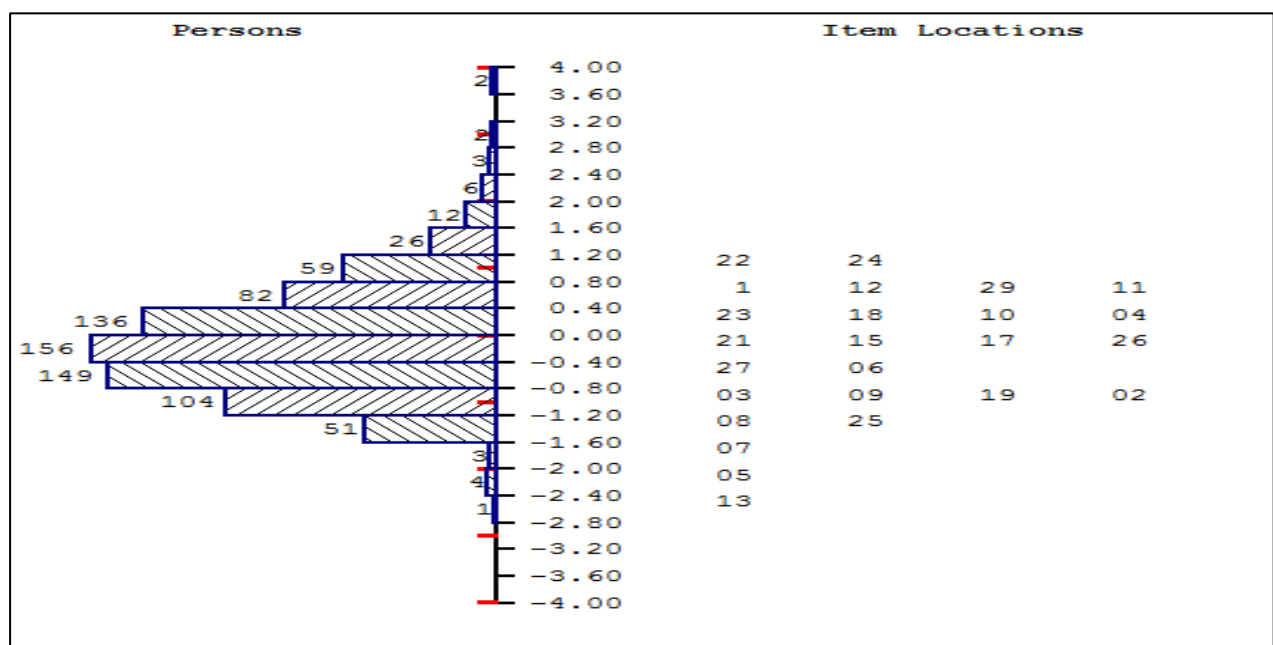


Figure 4.10: Item map excluding non-fitting items 14, 16, 20 & 28

#### 4.5.1 Item Characteristic Curves

Rasch analysis makes use of Item Characteristic Curves (ICC) as they are useful to represent the alignment between item difficulty and person ability. The ICC application gives a graphical display of performance in each item, which provides information about the relationship between the participants' ability and the likelihood of the participants getting the item right (Adewole & Ojo; 2017 p.22). The ICC were used to indicate a test-items' properties in terms of its difficulty index and discriminating index. It provides the researcher with comprehensive information about each test-item and may provide possible answers to some questions, like:

- (1) Does the item discriminate well between participants with a good conceptual understanding and those with a poor conceptual understanding?
- (2) How do the low/high ability participants respond to the item?

On an ICC, participants are represented on the horizontal axis from a low ability to a high ability. The likelihood of a participant choosing a correct response is represented by the vertical axis (from 0.0 to 1.0). An examination of participants' answers will be presented first, followed by a discussion of the validity evidence.

The expected and actual outcomes of items that fit the model can be represented on an ICC. In ICCs, groups of participants across the trait (referred to as class intervals) can be plotted against the expected model curve. When the group plots lay exactly on the curve a good fit of test-items are indicated. Over-discrimination can be indicated when class intervals are steeper than the model curve. Under-discrimination can be indicated when class intervals are flatter than the model curve (Pallant & Tennant, 2007).

It would be important to note that as participant ability varies, the probability of a correct response to a test-item will then also vary. Students with a poor conceptual understanding will in all likelihood have difficulty answering the test-items correctly. Regarding the ICC's such a student will be more inclined to approach zero on the horizontal axis. Students with a good conceptual understanding will in all likelihood be more inclined to approach 1 on the horizontal axis of an ICC.

#### 4.5.2 Discussion of Items

##### Question 1:

Question 1 has an item location value of 0.884, which can be regarded as a test-question that would function well within the sample. It has a fit residual value of 1.464 indicating that this test-item discriminates adequately as it falls within the  $\pm 2.5$  parameters. The solid curve represents the expected values for that specific item. Participants with a weaker ability tended to do better than expected in question 1 compared to students with a greater ability that performed slightly below expectation. At a 0 location (horizontal axis) the probability of choosing the correct answer is just below 0.3 (vertical axis), indicating that the sample experienced this test-item as relatively difficult.

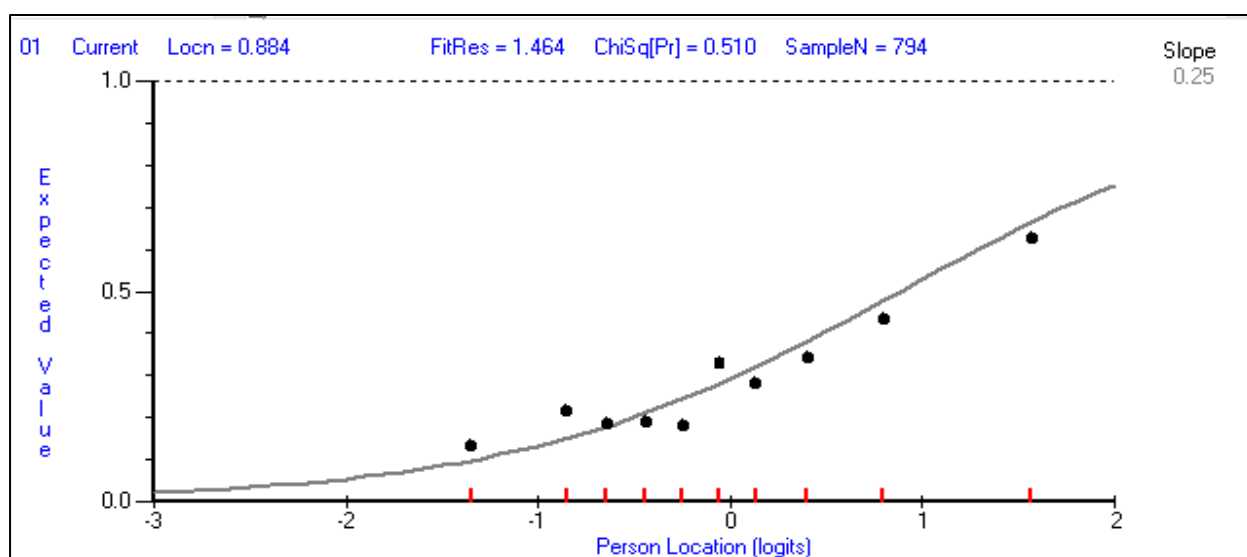


Figure 4.11.1: ICC for test-item 1

Question 1, shown in figure 4.11.2, deals with students' conceptual understanding of energy transfer at a microscopic level, related to Objective 9, within the outcome of current (Table 4.1 p. 56). Only twenty-nine per cent (Table 4.3 p.59) were successful in selecting option *D* as the correct answer.

The majority of students (thirty-two per cent, Table 4.3) selected option *A*, believing that charges are converted to light. For students to answer this question correctly they had to understand that charges are conserved, they cannot be converted into heat or light, and that the "friction" that the charges experience is in fact resistance that converts electrical potential energy to heat and light. The filament would heat up due to the collisions

between the charges and the atoms in the wire. Students choosing option A may have confused charge with energy.

- 1) Are charges used up in a light bulb, being converted to light?
- (A) Yes, charges moving through the filament produce “friction” which heats up the filament and produces light.
- (B) Yes, charges are emitted.
- (C) No, charge is conserved. It is simply converted to another form such as heat and light.
- (D) No, charge is conserved. Charges moving through the filament produce “friction” which heats up the filament and produces light.

**Figure 4.11.2: Question 1 (Correct Option: D)**

### Question 2:

At the 0 location (horizontal axis) the probability of choosing the correct answer was calculated just above 0.6 (vertical axis), indicating that the sample experienced this test-item to be less challenging. Test-item 2 revealed an item location value of -0.561 together with a fit residual value of 1.212, therefore, discriminating adequately. Participants with the highest ability found this question challenging as they are slightly below the model curve, while participants with the lowest ability performed above the curve. The item location value was calculated at -0,561, indicating that this question fits well within the sample.

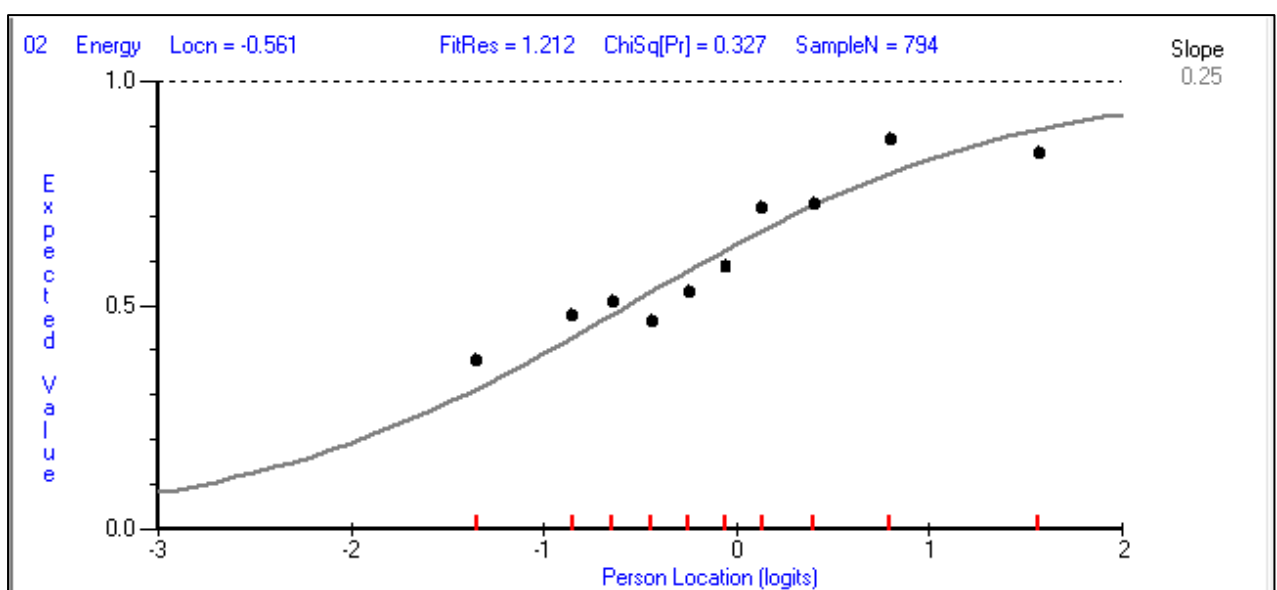


**Figure 4.12.1: ICC for test-item 2**

Question 2 in the DIRECT-instrument assesses students' conceptual understanding of how the power delivered to a particular resistor within a series circuit would be affected when another resistor is added in series. This test-item objective is to assess students' conceptual understanding of power (Objective 6; Table 4.1 p. 56) within the outcome of energy. As a sub-objective of this question, students need to understand that adding a resistor in series increases the total resistance, thus decreasing the current, which involves Objective 4 within the outcome of physical aspects of DC-electric circuits. Sixty-one per cent of all the participating students selected the correct option (option *B*), whereas twenty-six per cent chose option *C* as the popular wrong answer (Table 4.3 p.59). In choosing option *C*, students are revealing sequential reasoning, with the change only occurring "after" resistor *A*.

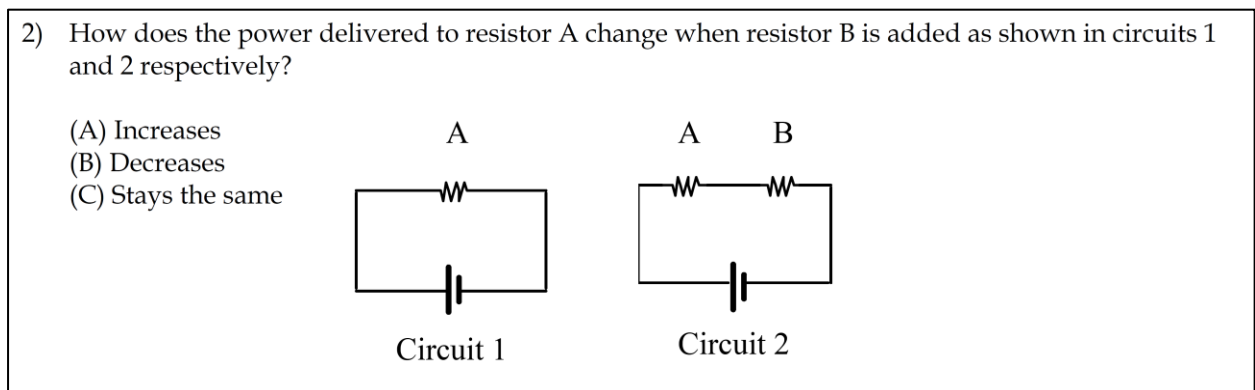


**Figure 4.12.2: Test-item 2 (Correct Option: *B*)**

### Question 3:

The ICC for test-item 3 (Fig. 4.13.1) indicates that participants with a lower ability as well as those with a higher ability performed as expected as they almost lie on the model curve. At 0 (horizontal axis), the probability of getting the item correct is above 0.6 (vertical axis), indicating that the sample experienced this test-item as less challenging. The item location value was calculated at -0.670 with a positive fit residual value of 0.851, implying that this test-item fits well within the sample.

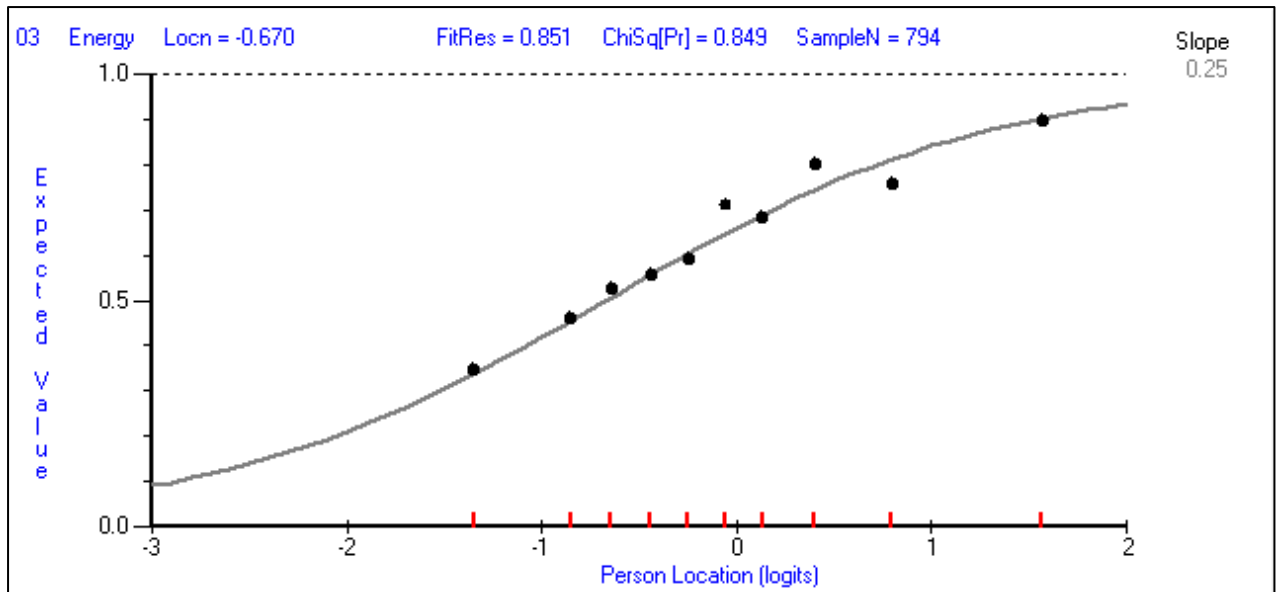


Figure 4.13.1: ICC for test-item 3

Question 3 (Fig. 4.13.2) is classified under objective 7 (Table 4.1 p. 56), assessing students' conceptual understanding of the conservation of energy. To answer this question correctly, students also need to reason conceptually about circuits that contain multiple cells, placed either in series or parallel. Sixty-three per cent (Table 4.5 p.59) of the students selected the correct answer.

The most popular wrong answer was *E*, selected by 13% of students (Table 4.3). Students selecting option *E* revealed battery superpositioning behind their reasoning, in that they believe two cells would provide a greater potential difference than one cell, regardless of the cell arrangement.

- 3) Consider the circuits shown below. Which circuit or circuits have the greatest energy delivered to it per second?

- (A) Circuit 1  
(B) Circuit 2  
(C) Circuit 3  
(D) Circuit 1 = Circuit 2  
(E) Circuit 2 = Circuit 3

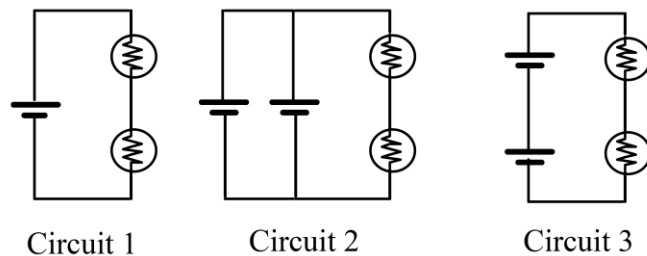


Figure 4.13.2: Test-item 3 (Correct Option: C)

If the students held the constant current source misconception, they may also have chosen  $E$ , reasoning that the current would add up for cells in series. This study could have benefitted from a three-tier test to get clarification on students' reasoning .

#### Question 4:

At the 0 location (horizontal axis) the probability of choosing the correct answer was calculated just above 0.3 (vertical axis), implying that the sample experienced this test-item to be relatively difficult. The ICC for test-item 4 (Fig.4.14.1) indicates that participants with a lower ability performed slightly worse than expected by the model curve. Those with a higher ability performed as expected as they lie on the model curve. The item location value was calculated at 0.761 with a negative fit residual value of -1.076, implying that this test item fits well within the sample.

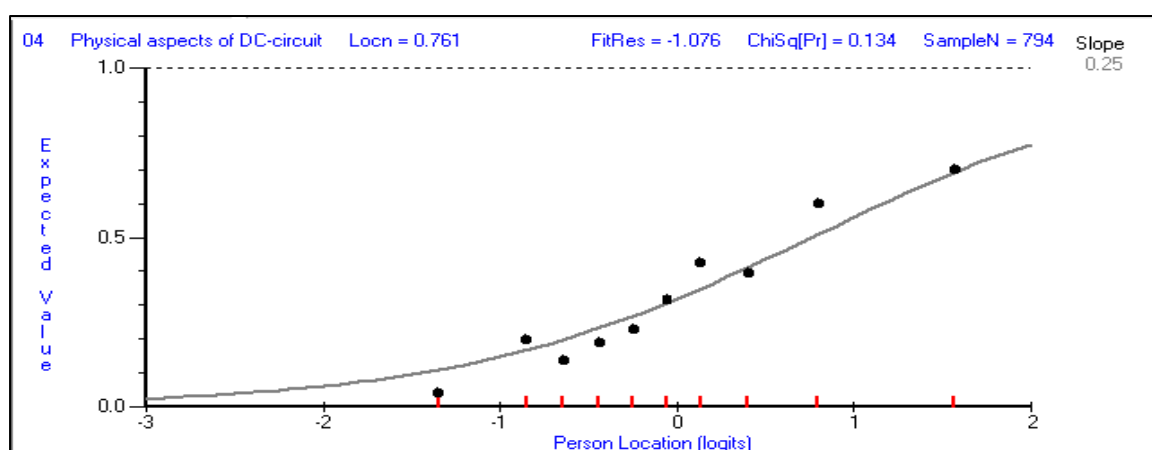
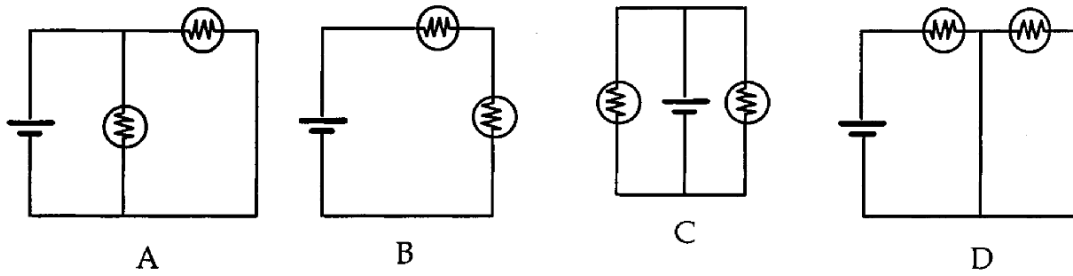


Figure 4.14.1: ICC for test-item 4

Question 4 in the DIRECT-instrument examines students' ability to interpret diagrams of circuits, including series; parallel, or combining the two (Table 4.1 p. 56). This question relates to Objective 5, which is a combination of Objectives 1 – 3, within the outcome *physical aspects* of an electric circuit. Only 32% of all the participants managed to select the correct answer, option  $D$  (circuits A and C). The most popular answer was option  $C$  (circuit C), as 43% made this choice (Table 4.3 p. 59) not realising that circuit A also represents a parallel circuit.

4) Consider the following circuits.



Which circuit(s) above represent(s) a circuit consisting of two light bulbs in parallel with a battery?

- (A) A
- (B) B
- (C) C
- (D) A and C
- (E) A, C, and D

Figure 4.14.2: Question 4 (Correct Option: D)

A slightly unconventional construction (specifically referring to option A) was used in question 4, which tested the conceptual understanding of how the arrangement of circuit components affects the whole circuit.

#### Question 5:

At the 0 location (horizontal axis) the probability of choosing the correct answer was calculated just below 0.9 (vertical axis), indicating that the sample experienced this test-item to be very easy. This is confirmed by the low item location value (-1.885) and the negative fit residual value (-1.028). Figure 4.15.1 indicates that most participants had a greater than 50% chance of choosing the correct option for Question 5 on the DIRECT-instrument. Even participants with a lower ability could easily answer this test-item correctly.

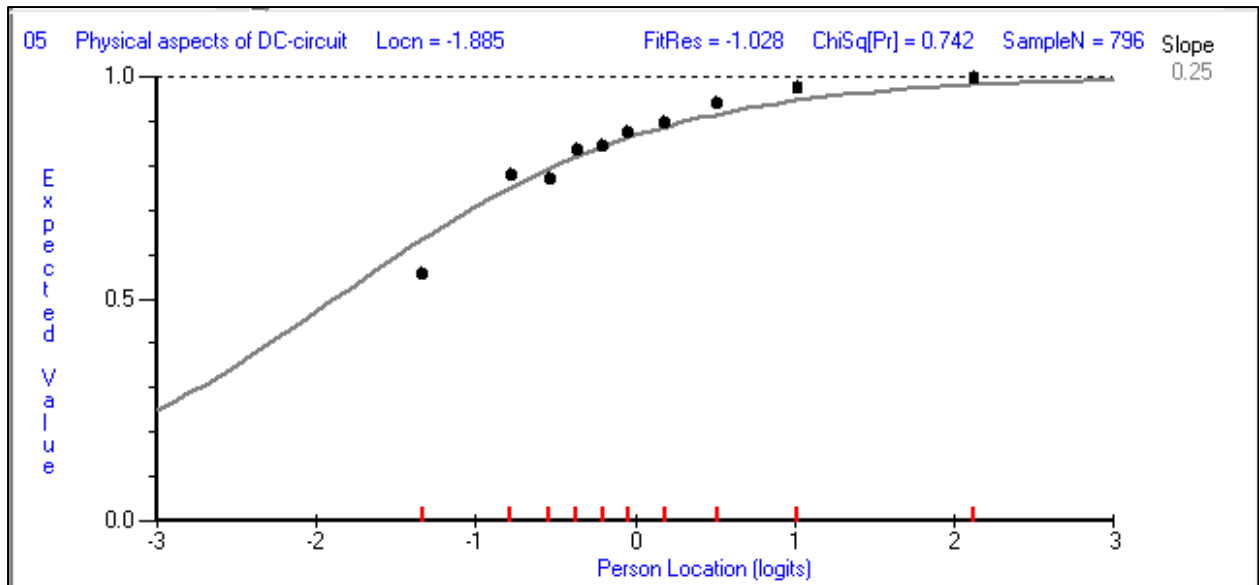
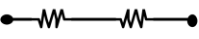


Figure 4.15.1: ICC for test-item 5

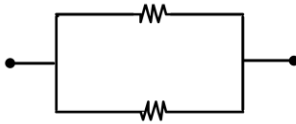
Question 5 examines whether students know the difference between the total that there resistance when two resistors are placed in series compared to when two resistors are placed in parallel. The objective (Objective 4) for this test-item is to determine students' conceptual understanding regarding the physical aspects of a DC-electric circuit (Table 4.1 p. 56). Nearly 83% of the participants were successful with this question (Table 4.3 p. 59), whereas only 8% selected option C as the most popular wrong answer.

5) Compare the resistance of branch 1 with that of branch 2. A branch is a section of a circuit. Which has the least resistance?

(A) Branch 1  
(B) Branch 2  
(C) Neither, they are the same



Branch 1



Branch 2

Figure 4.15.2: Test-item 5 (Correct Option: B)

### Question 6:

At the 0 location (horizontal axis), the probability of getting the item correct is slightly above 0.5 (vertical axis). The fit residual value (1.618) falls within the normal parameters of  $\pm 2.5$ , which indicates adequate fit to the model, and the question fits adequately within the sample. The plot of observed group responses deviates randomly from the model curve, indicating that not all high ability participants perform lower and low ability participants performed better.

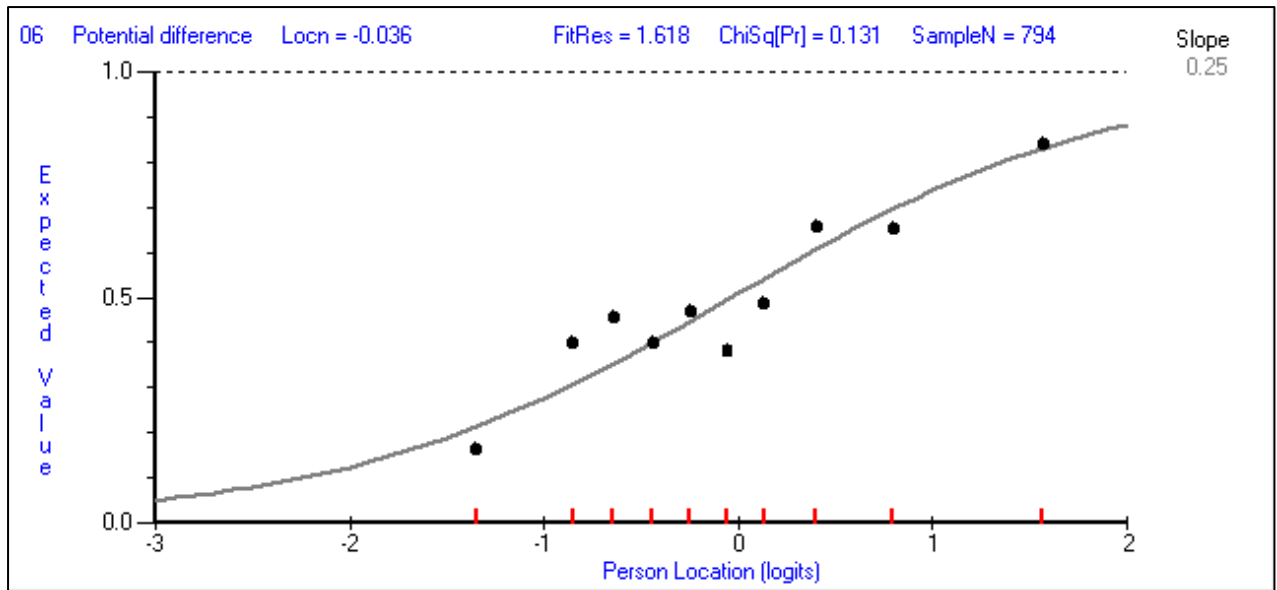


Figure 4.16.1: ICC for test-item 6

Question 6 (Figure 4.16.2) determines students' conceptual understanding regarding potential difference in a series circuit (Objective 11). The outcome being tested is potential difference (Table 4.1 p. 56). Forty-nine per cent of all the participants got this question correct, whereas the most popular wrong answer was option A selected by 19% (Table 4.5 p.59). It is possible that students selecting option A could have used the current consumption model of reasoning.

6) Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown below from highest to lowest.

(A) 1 and 2; 3 and 4; 4 and 5  
 (B) 1 and 2; 4 and 5; 3 and 4  
 (C) 3 and 4; 4 and 5; 1 and 2  
 (D) 3 and 4 = 4 and 5; 1 and 2  
 (E) 1 and 2; 3 and 4 = 4 and 5

Figure 4.16.2: Test-item 6 (Correct Option: E)

### Question 7:

At the 0 location (horizontal axis), the probability of getting the item correct is at 0.8 (vertical axis), implying that Question 7 was relatively easy. The fit residual value (0.818) falls within the normal range of  $\pm 2.5$ , indicating an adequate fit to the model.

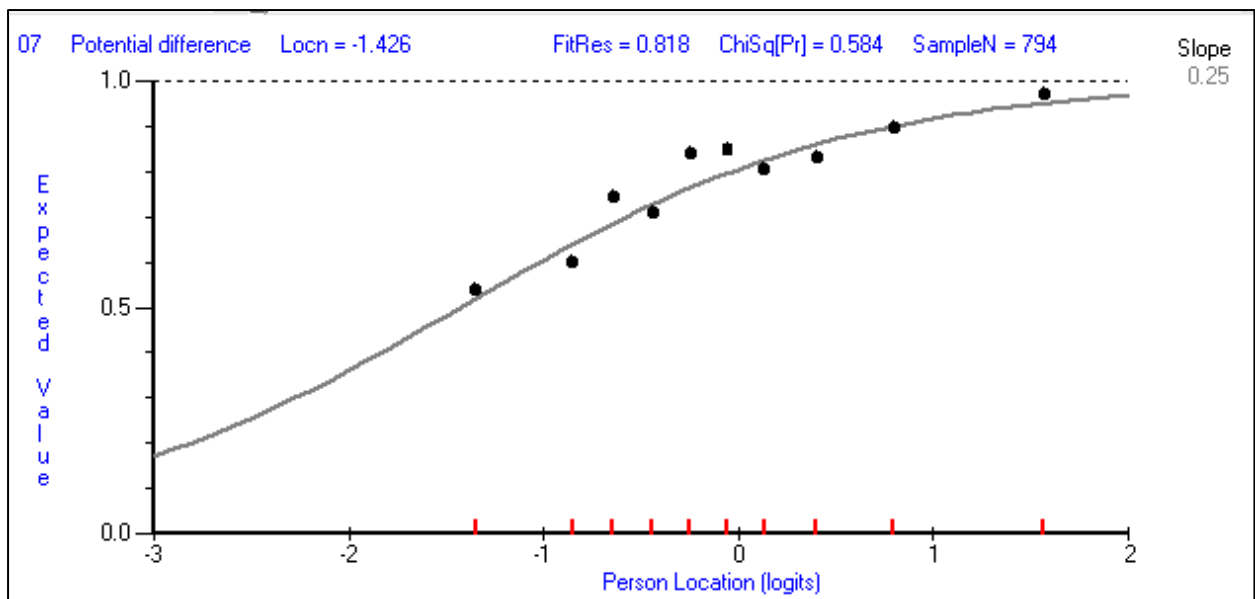
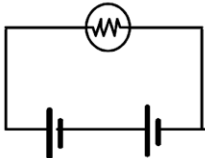


Figure 4.17.1: ICC for test-item 7

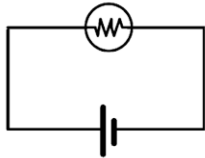
Question 7 examines students' conceptual understanding regarding the relationship between current and potential difference (Objective 10; Table 4.1 p.56). The outcome tested within the conceptual frame of this study was that of potential difference. Although 73% (Table 4.3 p. 59) got this question correct, twenty-one per cent did not understand that the potential difference would sum when cells are connected in series, selecting option C as the most popular wrong answer.

7) Compare the brightness of the bulb in circuit 1 with that in circuit 2. Which bulb is brighter?

(A) Bulb in circuit 1  
(B) Bulb in circuit 2  
(C) Neither, they are the same



Circuit 1



Circuit 2

Figure 4.17.2: Test-item 7 (Correct Option: A)

### Question 8:

At a 0 (horizontal axis) location, the probability of getting the item correct is just below 0.8 (vertical axis), implying that Question 8 was relatively easy. The fit residual value (-2.410) falls within the normal range of  $\pm 2.5$ , which indicates adequate fit to the model; however, it is very close to -2.5. The negative fit residual value obtained for this test-item suggests a higher level of discrimination. The ICC also confirms this level of discrimination in Fig

4.19.1. The plot of observed group responses slightly deviates from the model curve. The observed response is steeper than the ICC, indicating over-discrimination. Responses from the lower group (those portraying poor conceptual understanding) are below what is expected by the model and those for the higher group (those portraying good conceptual understanding) are above the model expectation.

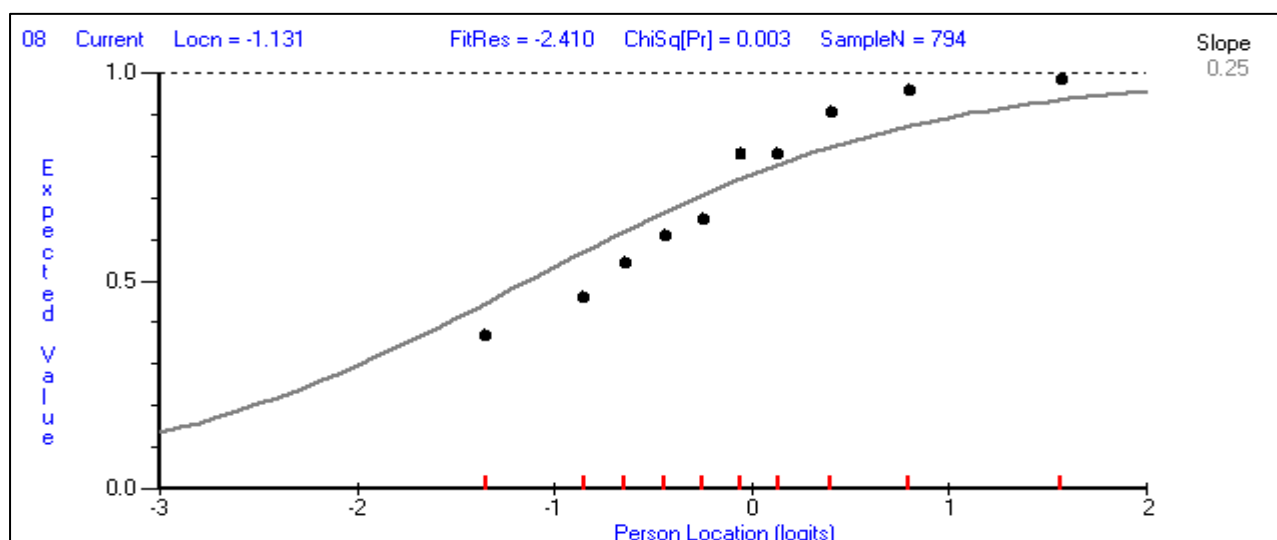


Figure 4.18.1: ICC for test-item 8

Upon examining Question 8 (Fig. 4.18.2), it seemed to be the most straightforward question on the DIRECT-instrument concerning student reasoning – current will either be conserved or it will not be conserved. The outcome being tested for was that of current where students had to apply the principle of conservation of current to a variety of circuits (Objective 8; Table 4.1 p.56).

Selecting either point 1 or point 2 would indicate the current consumption model. The difference between the two answers lies within the students' reasoning. If the student were using conventional current (which is the flow of positive charges), the student would reason that the current at point 1 is larger. If the student is using electron flow, then point 2 would be larger. Seventy-one per cent selected the correct option, while Option A was the most popular wrong answer, selected by 19% of the sample.

8) Compare the current at point 1 with the current at point 2. Which point has the larger current?

- (A) Point 1
- (B) Point 2
- (C) Neither, they are the same

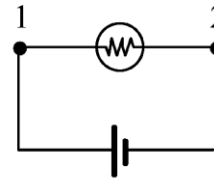


Figure 4.18.2: Test-item 8 (Correct Option: C)

### Question 9:

At a 0 (horizontal axis) location, the probability of getting the item correct is just above 0.6 (vertical axis), implying that Question 9 was relatively easy and would fit well within the sample. The fit residual value (-0.280) falls within the normal range of  $\pm 2.5$ , indicating adequate fit to the model.

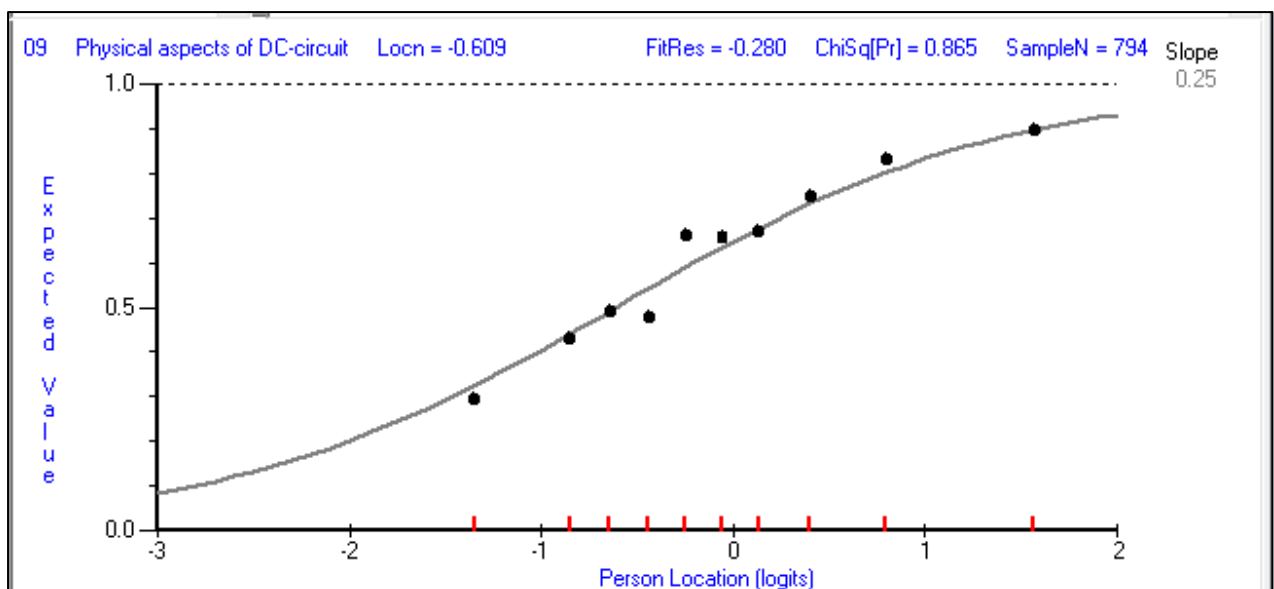


Figure 4.19.1: ICC for test-item 9

Question 9 determines students' conceptual understanding to identify a complete circuit (Objectives 2 and 3; Table 4.1 p. 56). The outcome being examined is the physical aspects DC-electric circuits. Question 9 consists of a "realistic" representation of a cell connected to a light bulb. Sixty-one per cent of the students chose the correct option (circuits A and C), identifying the complete circuits and the need for two contacts.

9) Which circuit(s) will light the bulb?

- (A) A
- (B) C
- (C) D
- (D) A and C
- (E) B and D

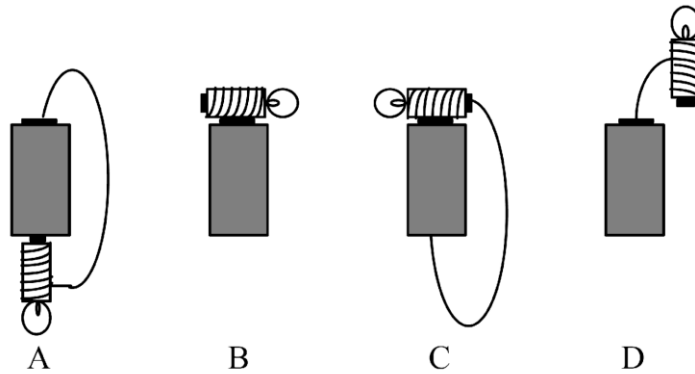


Figure 4.19.2: Question 9 (Correct Option: D)

Option A was the most popular wrong answer as 23% of the students selected this option (Table 4.3 p.59); believing only option A (circuit A) would light the bulb.

#### Question 10:

Figure 4.20.1 indicates that participants with a lower ability performed better in test-item 10 than expected, whereas participants with a higher ability performed worse than expected. The question arises: Why is it that the more able participants would think differently than expected, and why did the less able students perform better with this question?

At location 0 (horizontal axis) the probability of getting the item correct is above 0.3 (vertical axis), indicating that the item was relatively difficult. The fit residual value is somewhat larger than 2.5, indicating a significant deviation from the model. The positive fit residual value obtained for this test-item suggests under discrimination. This is also confirmed by the ICC in Figure 4.20.1. The plot of observed group responses deviates from the model curve. The observed response is flatter than the expected ICC, indicating under-discrimination.

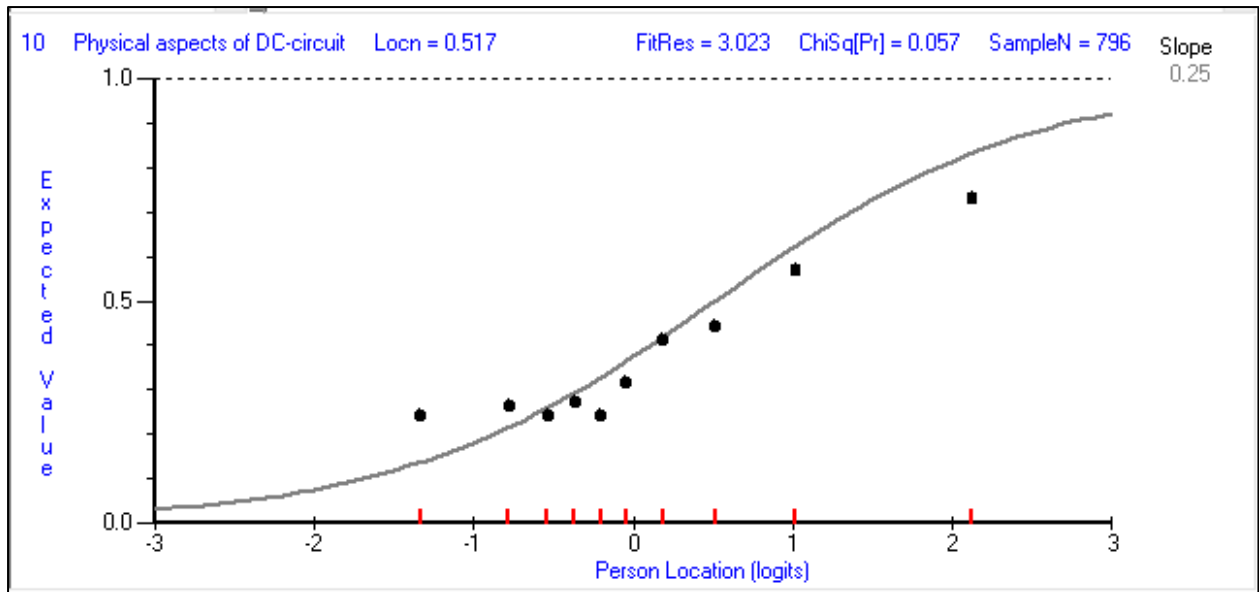


Figure 4.20.1: ICC for test-Item 10

Question 10 in the DIRECT-instrument (Fig. 4.20.2) deals with the outcome of physical aspects of a DC-electric circuit. This question's objective was for participants to identify and understand a short circuit (Objective 1; Table 4.1 p.56). The majority of participants (53%) chose option C (Table 4.3 p. 59), indicating that light bulb C would be the brightest. Only 34% managed to select the correct answer.

10) Compare the brightness of bulbs A and B in circuit 1 with the brightness of bulb C in circuit 2. Which bulb or bulbs are the brightest?

(A) A  
(B) B  
(C) C  
(D) A = B  
(E) A = C

Circuit 1 shows a battery connected to two light bulbs, A and B, in series. Circuit 2 shows a battery connected to a single light bulb, C, in series.

Figure 4.20.2: Test-Item 10 (Correct Option: E)

Hidden within this correct answer are potential misconceptions, which may explain why many of the less able students may have chosen this option. A student believing that current is consumed and the cell is a constant current source would argue that light bulbs A and C are equally bright since the cell supplies both with current,  $I$ , and B is dimmer because it comes “after” bulb A which has consumed some of the current. In this case, they may be viewing the bulbs in series or a series/parallel combination. The majority of

students chose option C, indicating that bulb C would be the brightest. They probably viewed the circuit with light bulbs A and B in series, believing that the “extra connection” does not influence the circuit, which is a well-known “short circuit misconception”.

From the discussion above, it is clear that Question 10 does not function effectively for the sample. This may be because short circuits are not emphasised in the CAPS curriculum, and participants might not have learned to recognise a short circuit or understand its effects. However, short circuits make up an essential part of understanding simple DC-electric circuits. Ideally, the SA curriculum on simple DC-electric circuits should be revised to emphasise short circuits.

### Question 11:

The ICC for test-item 11 (Fig. 4.21.1) in the DIRECT-instrument indicates at location 0 (horizontal axis) the probability of getting the item correct is above 0.2 (vertical axis), indicating that Question 11 was fairly hard for the participants to answer. Participants with a higher ability performed below model expectation, whereas participants with a lower ability performed according to the model expectation.

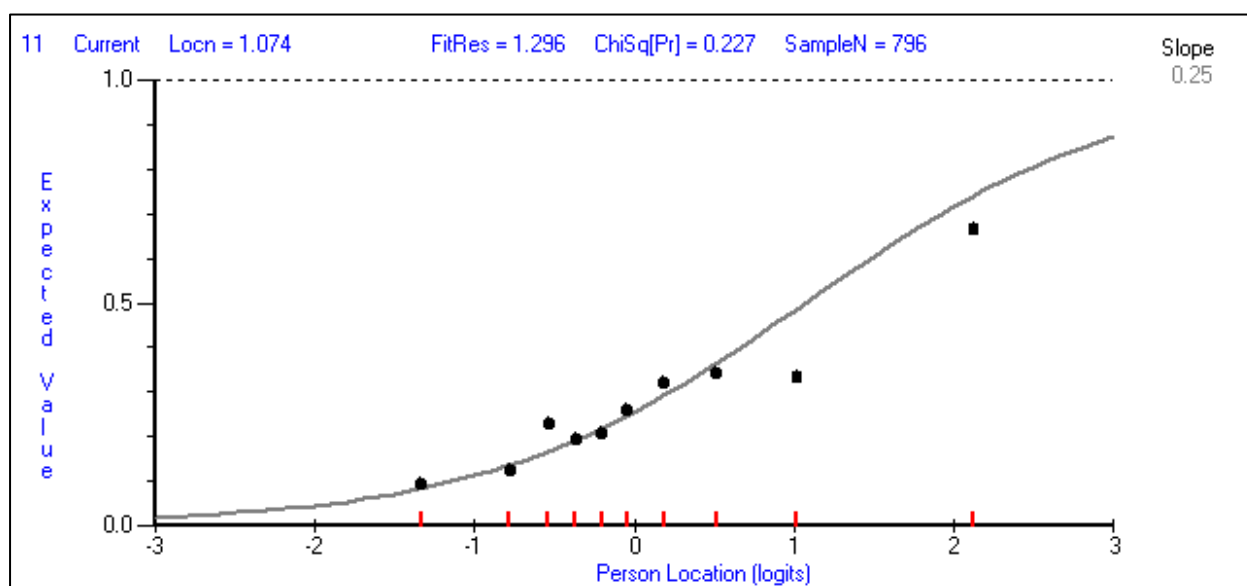


Figure 4.21.1: ICC for test-item 11

Question 11 assesses participant’s conceptual understanding regarding current using electrostatic terms (Table 4.1, Objective 9). The outcome of current is being investigated.

The most popular wrong answer was option *D* (41%), with only 23% of the students selecting the correct option (Table 4.3 p.59).

The conclusion can be made that this item is not suitable for this particular group of participants. It would be beneficial to refer to the NCS that the participants followed during their schooling. Neither CAPS nor the previous NCS in SA mentions how charged particles behave inside conducting wires and resistors. Some teachers might have taught these concepts to their learners, but it is not a required outcome.

- 11) Why do the lights in your home come on almost instantaneously?
- (A) Charges are already in the wire. When the circuit is completed, there is a rapid rearrangement of surface charges in the circuit.
  - (B) Charges store energy. When the circuit is completed, the energy is released.
  - (C) Charges in the wire travel very fast.
  - (D) The circuits in a home are wired in parallel. Thus, a current is already flowing.

**Figure 4.21.2: Test-item 11 (Correct Option: A)**

### Question 12:

At a person location of 0 (horizontal axis) the probability of getting the item correct is slightly below 0.3 (vertical axis), indicating that this was a relatively difficult test-item.

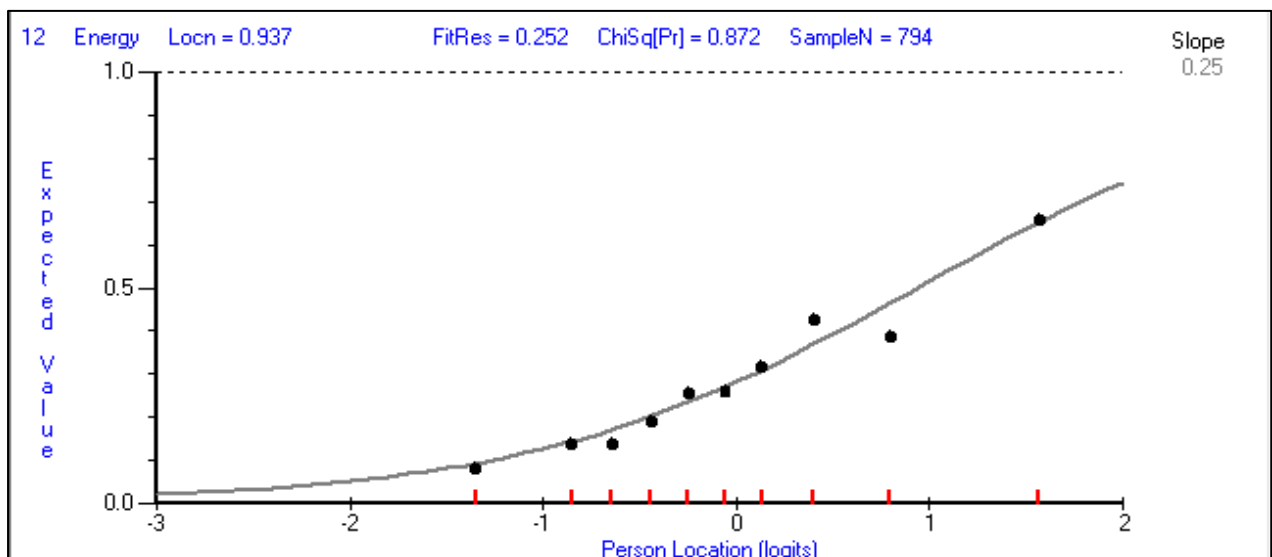


**Figure 4.22.1: ICC for test-item 12**

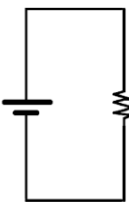
Question 12 (Fig. 4.22.2) determined students' conceptual understanding regarding the outcome of energy (Objective 6; Table 4.1 p. 56).

Only 28% managed to select the correct option. Option A was the most popular choice, with 34% believing that Circuit 1, with only one cell, would have the least amount of power delivered to the resistor (Table 4.3 p.59).

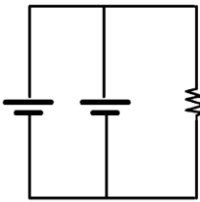
Errors seemed to be associated with what happens with the two cells in parallel. The battery superposition misconception were used when students selected Option B, believing that two cells will make the bulb twice as bright regardless of the arrangement.

12) Consider the power delivered to each of the resistors shown in the circuits below. Which circuit or circuits have the least power delivered to it?

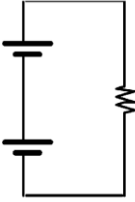
(A) Circuit 1  
 (B) Circuit 2  
 (C) Circuit 3  
 (D) Circuit 1 = Circuit 2  
 (E) Circuit 1 = Circuit 3



Circuit 1



Circuit 2



Circuit 3

Figure 4.22.2: Question 12 (Correct Option: D)

### Question 13:

The ICC (Fig.4.23.1) for Question 13 indicates that the group of participants with the best conceptual understanding of DC-electric circuits approaches 1 on the vertical axis, and at a person location of 0 the probability of answering this question correctly is almost above 0.9 on the vertical axis, indicating that this test-item was very easy – the easiest test-item in the diagnostic tool. Most of the lower and highest response group plots are on the expected model curve.

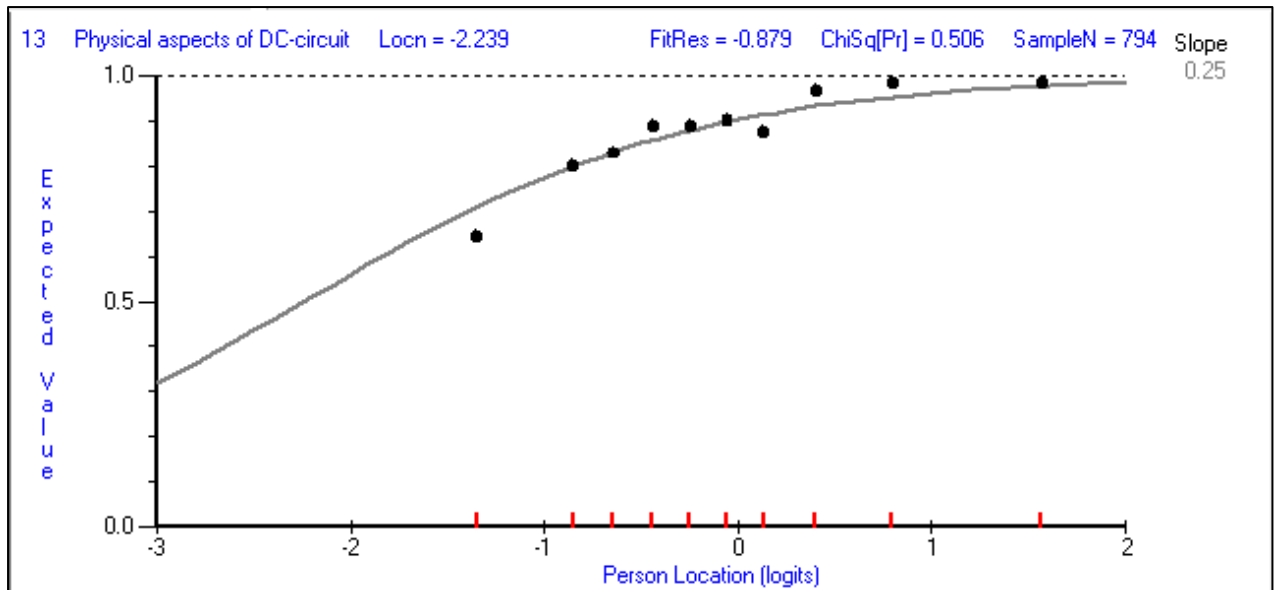


Figure 4.23.1: ICC for test-item 13

Question 13 is a diagram interpretation question that required participants to translate a picture of a “realistic” circuit to a schematic diagram. This test-item outcome dealt with students’ conceptual understanding regarding the physical aspects of a DC-electric circuit (Objective 5; Table 4.1 p.56). Most participants could recognise the correct schematic representation of a simple DC-electric circuit. The correct option for Test-item 13 is option A, and it was the most popular choice (Table 4.3). Eighty-seven per cent (78%) of the participants answered this question correctly (Table 4.3 p.59), and 4.5% of the participants chose option B as the most popular wrong answer.

13) Which schematic diagram best represents the realistic circuit shown below?

- (A) A
- (B) B
- (C) C
- (D) D
- (E) None of the above

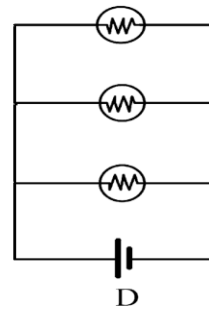
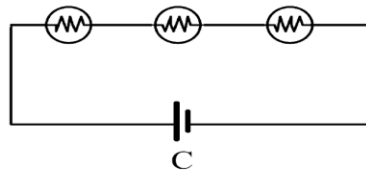
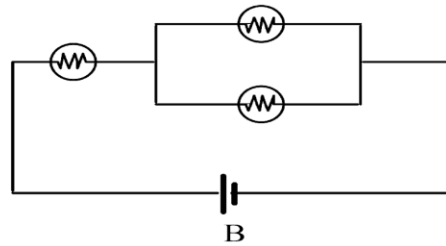
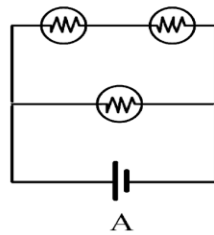
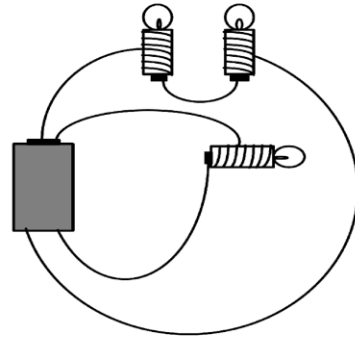


Figure 4.23.2: Test-item 13 (Correct Option: A)

### Question 15:

At a person location of 0, the probability of getting this test-item correct is just above 0.4. The positive fit residual value of 2.678 for the ICC, referring to Test-item 15 (Fig.4.24.1 p. 92) is indicative of under-discrimination and is slightly above the acceptable maximum value of +2.5. this under-discrimination is also confirmed by the ICC in Figure 4.24.1. The theoretical curve is flatter than expected as the group responses deviate from the model curve. Participants with a greater ability found this question to be challenging.

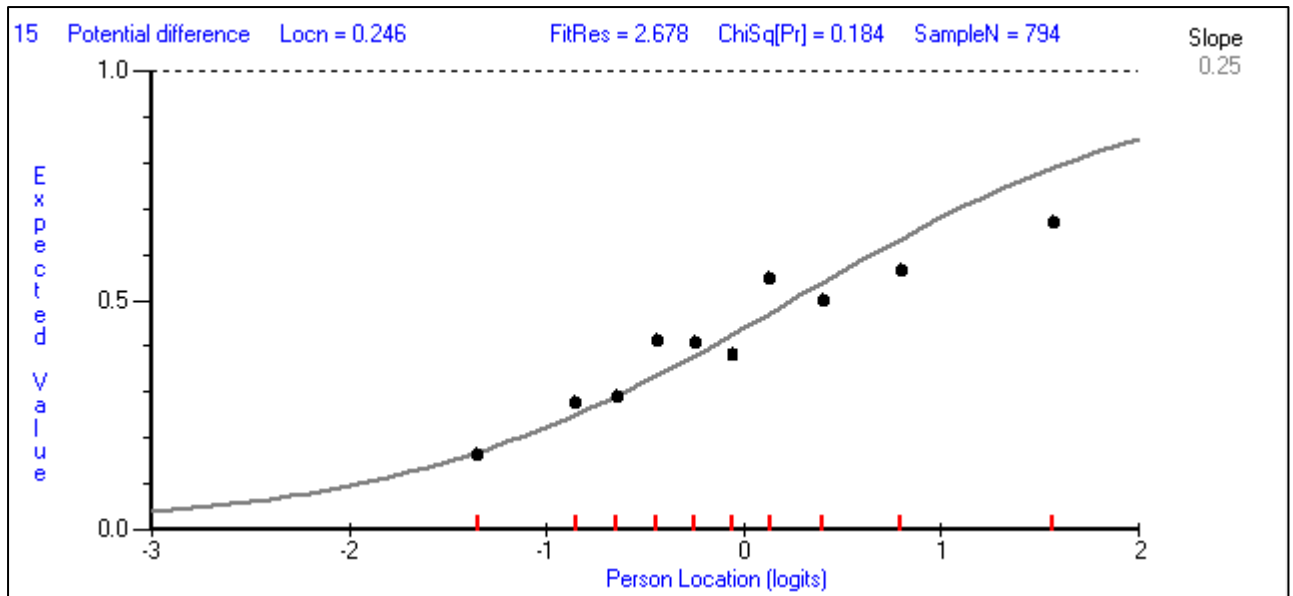


Figure 4.24.1: ICC for test-item 15

Test-item 15 (Fig. 4.24.2) examines students' understanding of the potential difference across parallel-connected resistors. The objective for this test-item is to determine students' conceptual understanding regarding potential difference (Objective 11; Table 4.1 p.56). The outcome being tested for was potential difference.

Approximately 42% answered this question correctly. Thirty-nine per cent chose option A (Table 4.3 p.59) as the most popular wrong answer. This suggests that the participants confused voltage and current and/or believed the cell was a constant current source.

15) What happens to the potential difference between points 1 and 2 if bulb A is removed?

- (A) Increases
- (B) Decreases
- (C) Stays the same

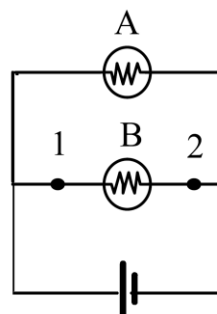


Figure 4.24.2: Test-item 15 (Correct Option: C)

### Question 17:

At a person location of 0, the probability of getting this test-item correct is just above 0.4, indicating that this test-item fits the sample well. The ICC for this item shows that participants with a low ability (-1.4 on the horizontal axis) had a very low probability of selecting the correct option for this test-item. The item location value (0.259) and the negative fit residual value (-0.599) indicate some over discrimination, implying that the sample experienced this test-item as less challenging.

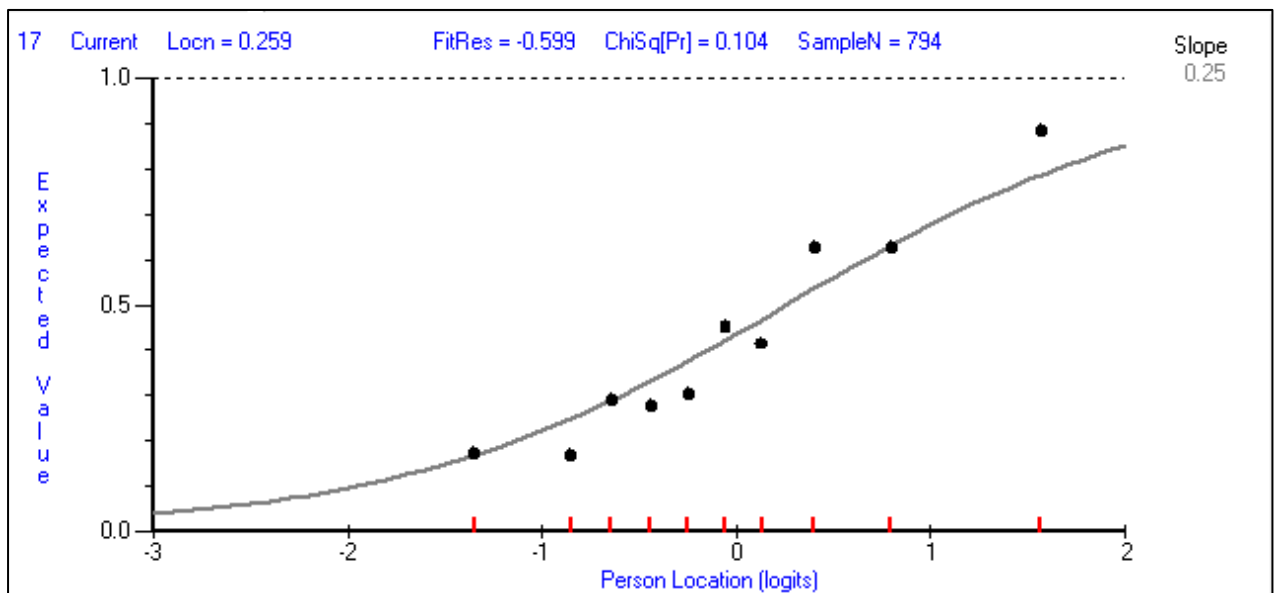


Figure 4.25.1: ICC for test-item 17

In Question 17, the outcome being tested for is current. The objective for this test-item was to assess whether students could apply the principle of conservation of current (Objective 8; Table 4.1, p.56). Although 42% (Table 4.3 p.59) selected the correct option, 26% chose Option C, the most popular wrong answer. This is indicative of the empirical rule model, suggesting that the students think the current is least in the branch that is “further away” from the cell.

17) Rank the currents at points 1, 2, 3, 4, 5, and 6 from highest to lowest.

- (A) 5, 1, 3, 2, 4, 6
- (B) 5, 3, 1, 4, 2, 6
- (C) 5 = 6, 3 = 4, 1 = 2
- (D) 5 = 6, 1 = 2 = 3 = 4
- (E) 1 = 2 = 3 = 4 = 5 = 6

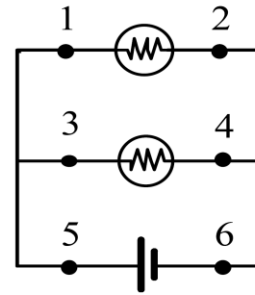


Figure 4.25.2: Question 17 (Correct Option: D)

### Question 18:

At a person location of 0, the probability of getting this test-item correct is just below 0.4. The item location value (0.585) and the positive fit residual value (1.124) indicate that this test-item would fit the sample well.

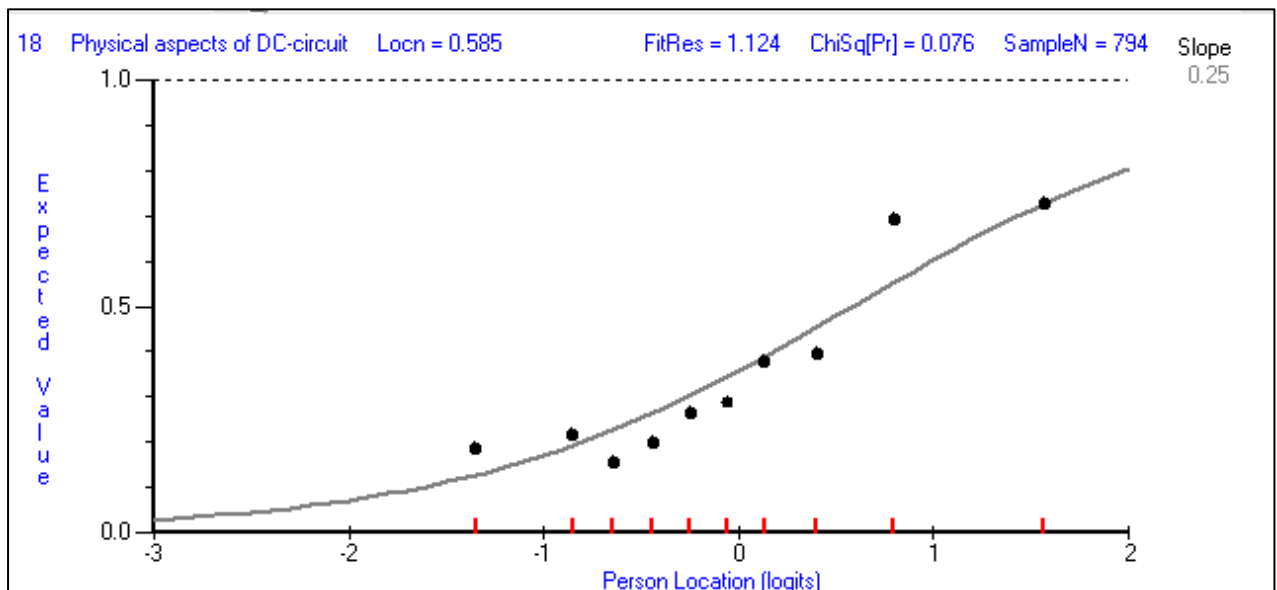


Figure 4.26.1: ICC for test-item 18

The outcome being tested for in Test-item 18 is the physical aspects of DC-electric circuits. The objective is for students to identify the functional two-endedness of a light bulb. Students were also required to identify a complete circuit, indicating conceptual understanding regarding that a closed circuit is a requirement for current to flow (Objective 2 & 3; Table 4.1 p.56).

This question displays four circuit diagrams, each containing a cell, connecting wires, and a light bulb in a socket. Thirty-five per cent of the participants could select the correct option, being circuit D (Option C). The majority (56%) of participants identified circuits B and D as both being able to light the bulb (Option D), failing to recognise that circuit B contains an additional wire creating a short in the circuit (Table 4.3 p.59).

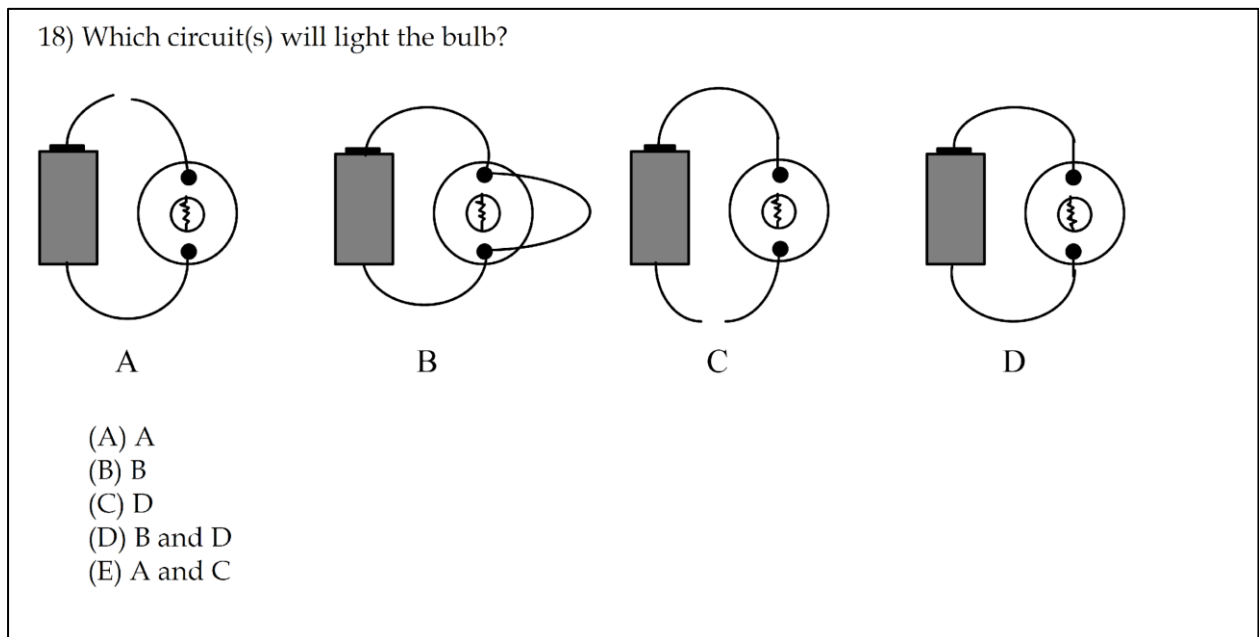


Figure 4.26.2: Question 18 (Correct option: C)

It seems that students can identify complete circuits but were unable to eliminate those that include short circuits.

Students might also have had difficulty understanding the realistic representation of a light bulb in a socket as it is not emphasised within the SA CAPS.

#### Question 19:

The ICC for Question 19 (Fig. 4.27.1) illustrates that at location 0 (on the horizontal axis) the probability of answering this test-item correctly is just above 0.6, indicating that this test-item fits the sample well.

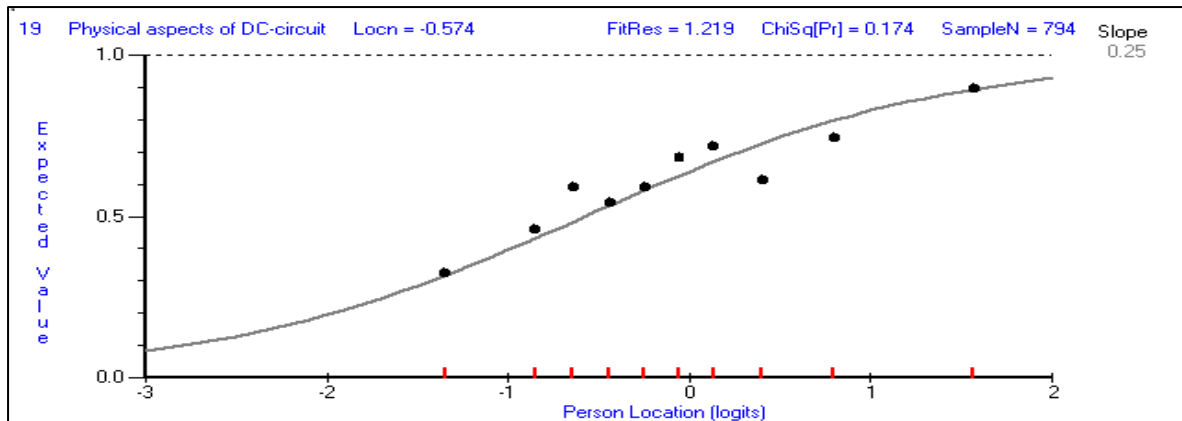


Figure 4.27.1: ICC for test-item 19

The outcome being tested for is the physical aspects of a DC-electric circuit. The objective of this question was for students to identify a short circuit (Objective 1; Table 4.1 p. 56).

The question asks how the brightness of two light bulbs would be affected when a connecting wire is inserted between two points that are at the same potential. In essence, it will not affect the brightness of bulbs A and B as the addition of a wire between points 1 and 2 does not influence the current, nor does it influence the parallel connection of the two bulbs. Sixty per cent of the participants answered this question correctly (Table 4.3 p.59). Participants making the correct selection conceptually understood that there is no potential difference between points 1 and 2 on the circuit diagram. The most popular wrong answer was option B, with 17% of the students making this selection.

19) What happens to the brightness of bulbs A and B when a wire is connected between points 1 and 2?

(A) Increases  
(B) Decreases  
(C) Stays the same  
(D) A becomes brighter than B  
(E) Neither bulb will light

Figure 4.27.2: Question 19 (Correct Option: C)

### Question 21:

The ICC for test-item 21 (Fig.4.28.1) indicates that at location 0 (horizontal axis) the probability of selecting the correct option would be at 0.5, indicating that this test-item would function well within the sample.

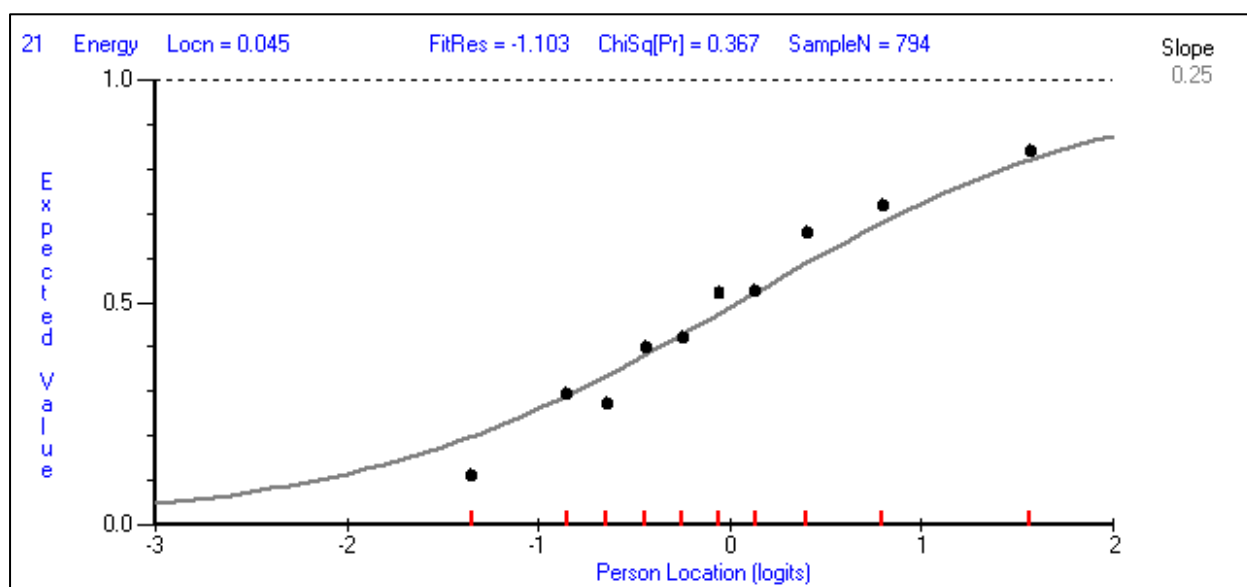


Figure 4.28.1: ICC Test-item 21

The outcome being tested for in Question 21 is that of energy within a DC-electric circuit. The objective for Question 21 (Fig. 4.28.2) was to assess if students conceptually understand the principle of conservation of energy within a DC-electric circuit, with the cell being the source of energy (Objective 7; Table 4.1 p.56). Forty-eight per cent (Table 4.5) answered this question correctly. The most popular wrong answer was option C (Table 4.3 p.59), selected by 22.5%. Students who reasoned that current is being consumed may have selected option C. Students reasoning that the cell is a source of constant current would have selected option E (14%).

21) Compare the energy delivered per second to the light bulb in circuit 1 with the energy delivered per second to the light bulbs in circuit 2. Which bulb or bulbs have the least energy delivered to it per second?

- (A) A
- (B) B
- (C) C
- (D) B = C
- (E) A = B = C

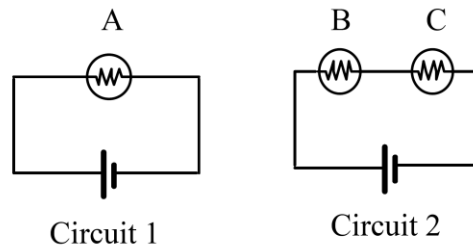


Figure 4.28.2: Question 21 (Correct Option: D)

### Question 22:

The ICC for test-item 22 (Fig.4.29.1) indicates that at 0 (horizontal axis) the probability of selecting the correct option would be slightly above 0.2, indicating that this test-item can be classified as being hard. The ICC also indicates that the majority of group respondents deviates from the model curve. The fit residual value (1.340) together with the person location value (1.247) indicates that this test-item under discriminates within the sample.

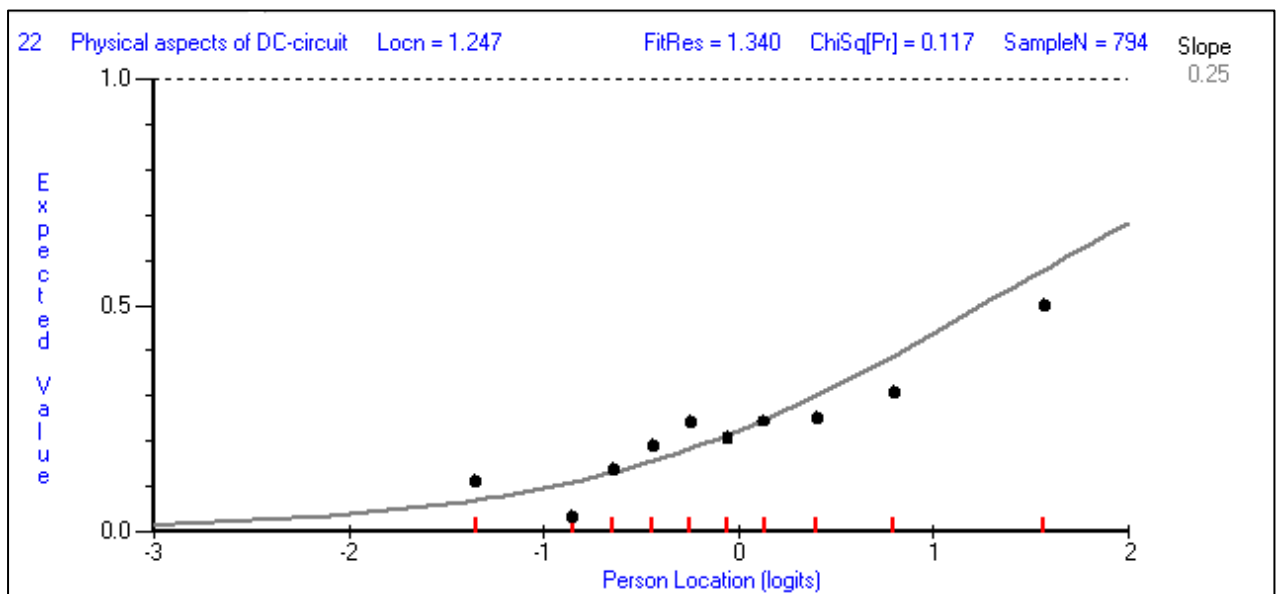


Figure 4.29.1: ICC for test-item 22

The outcome being tested for in Question 22 is the physical aspects of a DC-electric circuit. The objective is for students to interpret a variety of circuit diagrams (Objective 5;

Table 4.1 p. 56). Only 22% (Table 4.3 p.59) of the students answered this question correctly. Option E (47% for both circuits C and D) was the most popular wrong answer.

Question 22 (Fig. 4.29.1) might have been flawed in the way it was asked. Students might have understood the concept being tested for, but may have made a mistake on their answer sheet as the multiple-choice options' labels may be confused with the labels of bulbs in the circuit. Answer B (the correct answer) indicates a selection of circuit C, while answer C indicates a selection of circuit D. Students who wanted to answer circuit C may have mistakenly selected option C on their answer sheets. However, option E's large preference indicates that most students believed that two of the circuits are correct, rather than simply confusing letters of the alphabet.

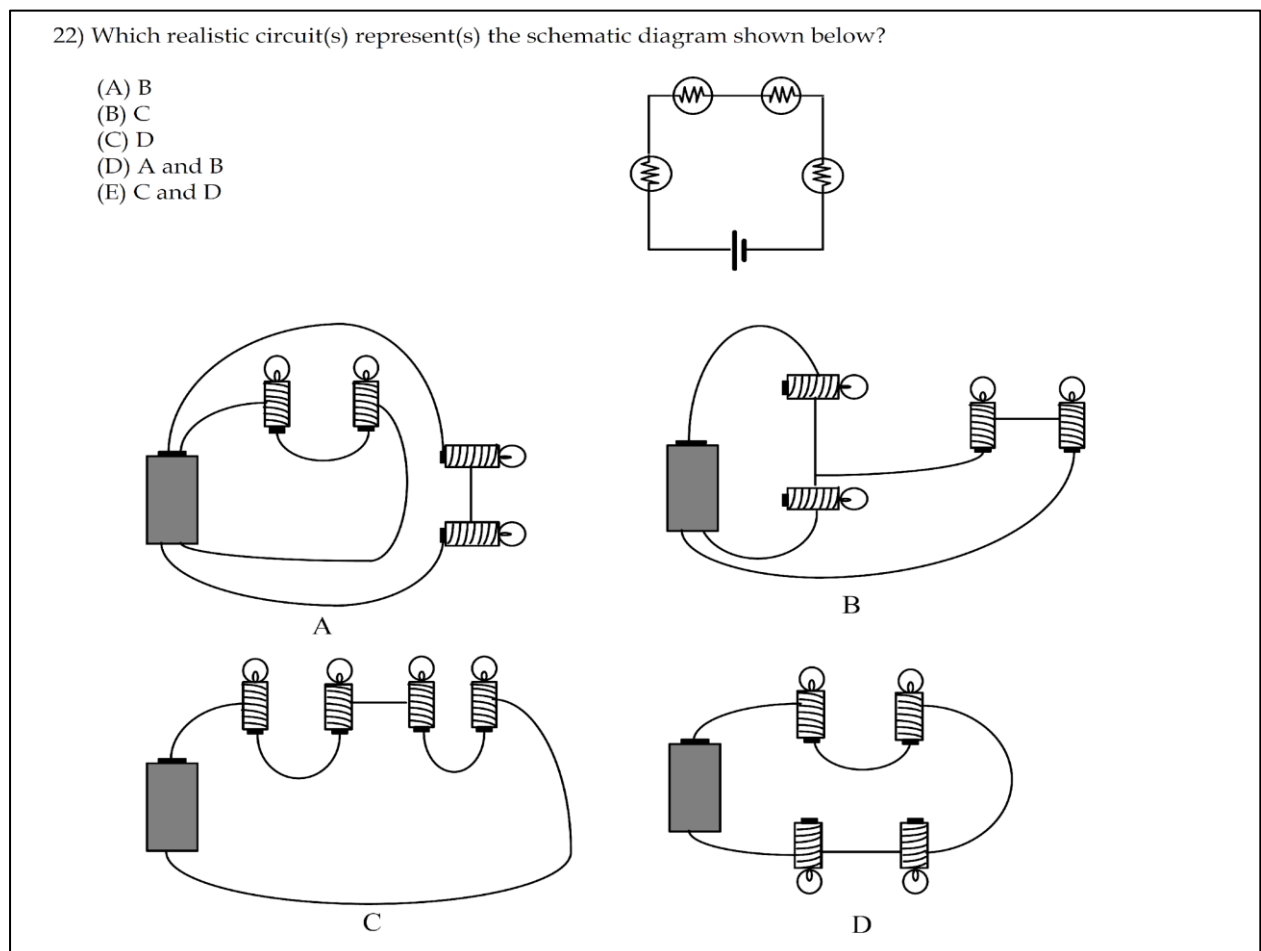


Figure 4.29.2: Question 22 (Correct Option: B, representing circuit C)

### Question 23:

At a person location of 0 (horizontal axis) the probability of choosing the correct response for Test-item 23 (Fig. 4.30.1) is at 0.4. The item location value (0.445) together with the negative fit residual value (-1.205) indicates that this question would fit well within the sample.

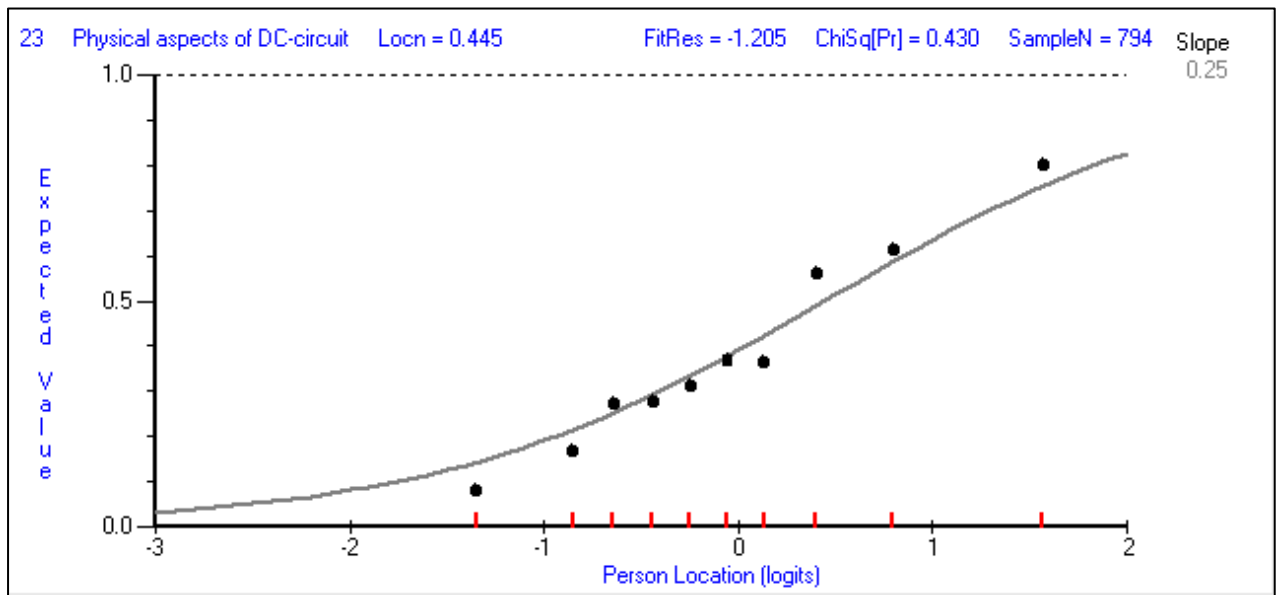


Figure 4.30.1: ICC for test-item 23

Question 23 determines students' conceptual understanding regarding resistance, knowing that resistance is a property of the material of the resistor (Objective 4, Table 4.1 p. 56). The outcome being tested is the physical aspects of a DC-electric circuit.

Thirty-eight per cent of the students answered this question correctly (Table 4.3 p.59). Some students may have reasoned that since there was not any current present after the switch was opened, there was “nothing for the resistor to resist” and therefore no resistance. Therefore, selecting Option D, believing the resistance would go to zero (34% of students chose option D, which was the most popular wrong answer). This indicates that they do not understand that resistance is a property of the material.

23) Immediately after the switch is opened, what happens to the resistance of the bulb?

- (A) The resistance increases.
- (B) The resistance decreases.
- (C) The resistance stays the same.
- (D) The resistance goes to zero.

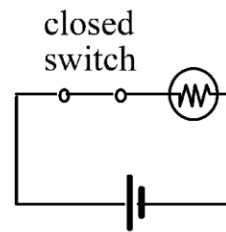


Figure 4.30.2: Question 23 (Correct Option: C)

Question 23 poses a problem since, depending on the question's interpretation, there can be two correct alternatives. The question assesses students' conceptual understanding regarding resistance. Students with a good conceptual understanding may reason that the resistance decreases somewhat because of decreasing temperature when the current decreases and becomes zero. However, option *B* was chosen by a small group (11%) of participants, indicating that it was not a serious problem in this sample.

It should be noted that the same problem emerged in the original study (Engelhardt, 1997). However, when developing version 1.1 of the DIRECT-instrument, an additional alternative was added, which was that the resistance goes to infinity. None of the wording changed. The results obtained for Test-item 23 in version 1.1 were similar compared to Test-item 23 in version 1.0. This convinced the developers of the test that the item was not problematic.

According to Engelhardt (1997), "the question intends that there is not sufficient time to change the filament's temperature so that the resistance stays the same. If students do not interpret the question correctly, then answer *B* should also be counted as "correct" (p.102). Engelhardt continued by stating that "this question could be clarified by adding that there is no temperature change. Still, the researcher feels that this would unduly influence the students' thinking toward the correct answer by aiding them to recall information from the classroom or text" (p. 151). Another option is to change the diagram and just replace the bulb with an ohmic resistor. These are changes that can be considered when validating the DIRECT-instrument for a SA context.

#### Question 24:

Upon examination of Test-item 24, the ICC (Fig.4.31.1) indicates that this question was challenging for participants having a lower ability. Responses from the highest group (portraying a better conceptual understanding) are above the expected model curve and therefore performed better than expected. Responses from the lowest group (portraying poor conceptual understanding) are below the expected model curve. The fit residual value (-1.388) falls within the accepted range.

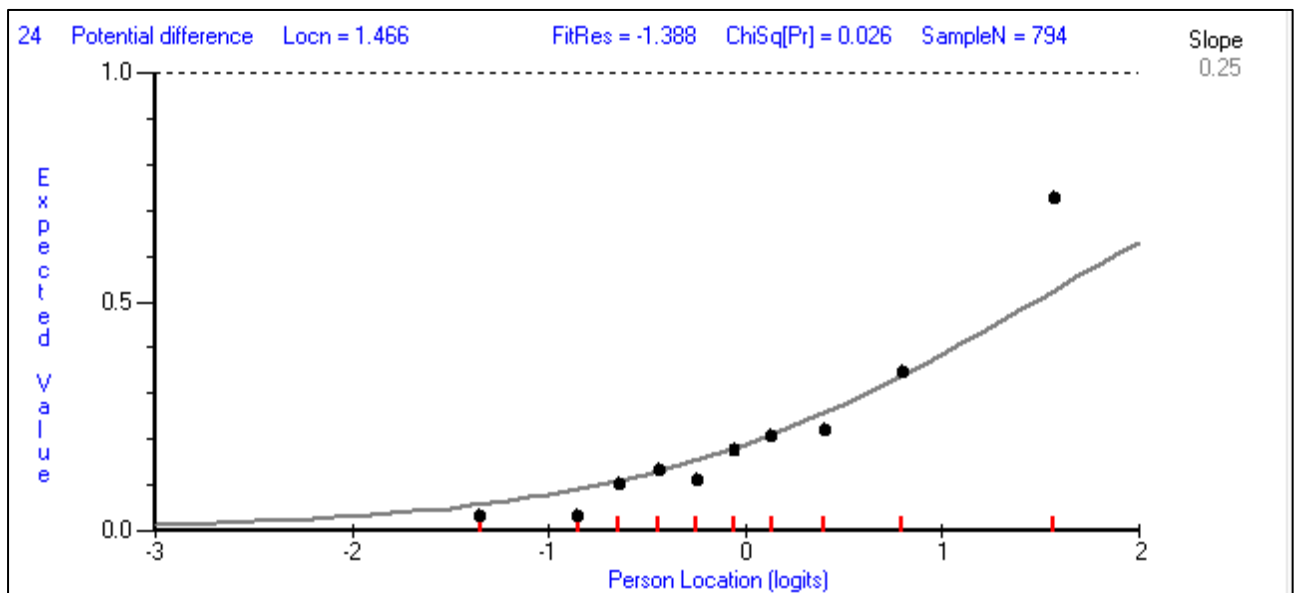


Figure 4.31.1: ICC for test-item 24

At a person location of 0 (horizontal axis) the probability of choosing the correct response for Test-item 24 (Fig. 4.31.1) is 0.2 on the vertical axis, indicating that participants found this test-item challenging. The probability of a correct response is low for most of the ability scale and increases only when the higher ability levels are reached. Even at the highest ability level shown (above + 2), the probability of a correct response is only 0.8 for this item.

The outcome being tested for in Question 24 is that of potential difference. The objective for this test-item was to assess students' conceptual understanding of potential difference supplied by a cell (Objective 11; Table 4.1 p. 56).

- 24) If you double the current through a battery, is the potential difference across a battery doubled?
- (A) Yes, because Ohm's law says  $V = IR$ .
  - (B) Yes, because as you increase the resistance, you increase the potential difference.
  - (C) No, because as you double the current, you reduce the potential difference by half.
  - (D) No, because the potential difference is a property of the battery.
  - (E) No, because the potential difference is a property of everything in the circuit.

**Figure 4.31.2: Test-item 24 (Correct Option: D)**

Fifty-eight per cent of the participants chose option A (Table 4.3 p.59), which was the most popular wrong answer. The correct response is however, option D, where only 20% answered correctly.

One might speculate that the reasoning behind participants' incorrect thinking can be ascribed to the emphasis that is often placed on using Ohm's Law to deal with any kind of circuit problem. Furthermore, learners are not necessarily taught the rationale behind Ohm's Law, where current is a consequence, not a cause. Little attention is given to conceptually understand that the voltage across the cell refers to potential energy provided per coulomb, an inherent property of the cell.

Question 25:

At a person location of 0 (horizontal axis) the probability of participants choosing the correct response is above 0.7 (vertical axis Fig. 4.32.1). With an item location value of -0.916, together with a fit residual value of -0.767, this test-item can be classified as being easy.

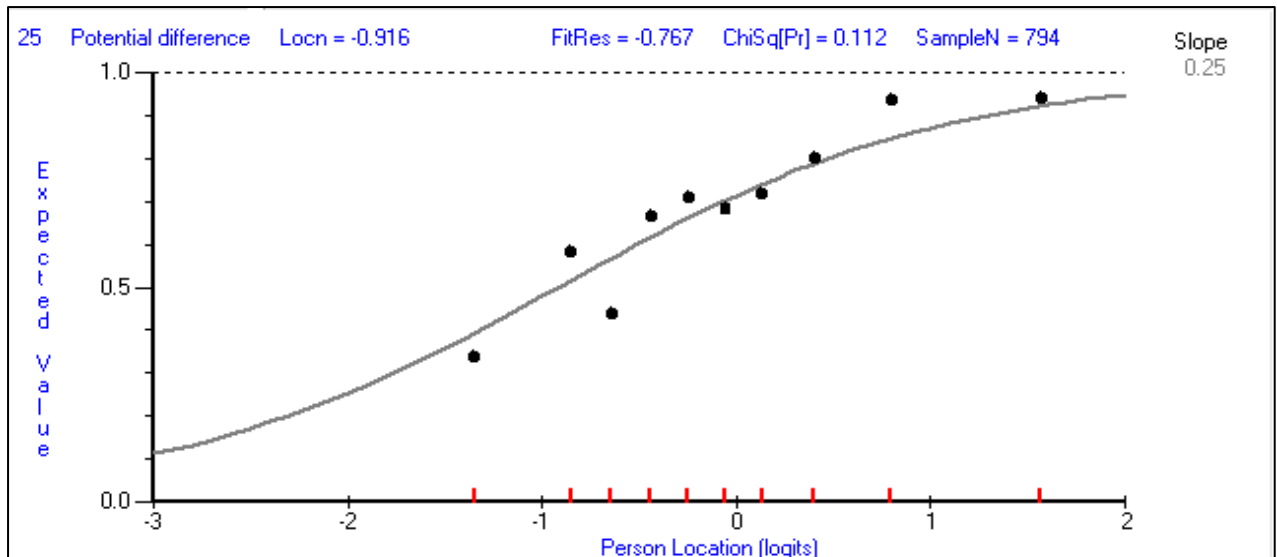


Figure 4.32.1: ICC for test-item 25

The outcome being tested for in Question 25 was that of potential difference. The objective was to determine students' conceptual understanding regarding current and potential difference (Objective 10 – Table 4.1 p. 56).

25) Compare the brightness of bulb A in circuit 1 with bulb A in circuit 2. Which bulb is brighter?

(A) Bulb A in circuit 1  
(B) Bulb A in circuit 2  
(C) Neither, they are the same

Circuit 1

Circuit 2

4.32.2: Question 25 (Correct Option: A)

Sixty-eight per cent (Table 4.3 p.59) of the students selected the correct option for this question. Option C was the most popular wrong answer, as 24% of the students made this selection. There might be two reasons why students would want to make this selection. Firstly, they do not understand that the current in Circuit 2 is less than in circuit1, so in circuit 2, both bulbs are dimmer compared to the light bulb in circuit 1. Secondly, they may also think that in Circuit 2, light bulb A receives "more current" compared to light bulb B, which would be an indication of the current consumption model.

### Question 26:

At a person location of 0 (horizontal axis) the probability of participants choosing the correct response is above 0.4 (vertical axis). This test-item would fit well within the sample. The item location value (0.236) and the fit residual value (-2.775) indicate that participants found this test-item moderately difficult.

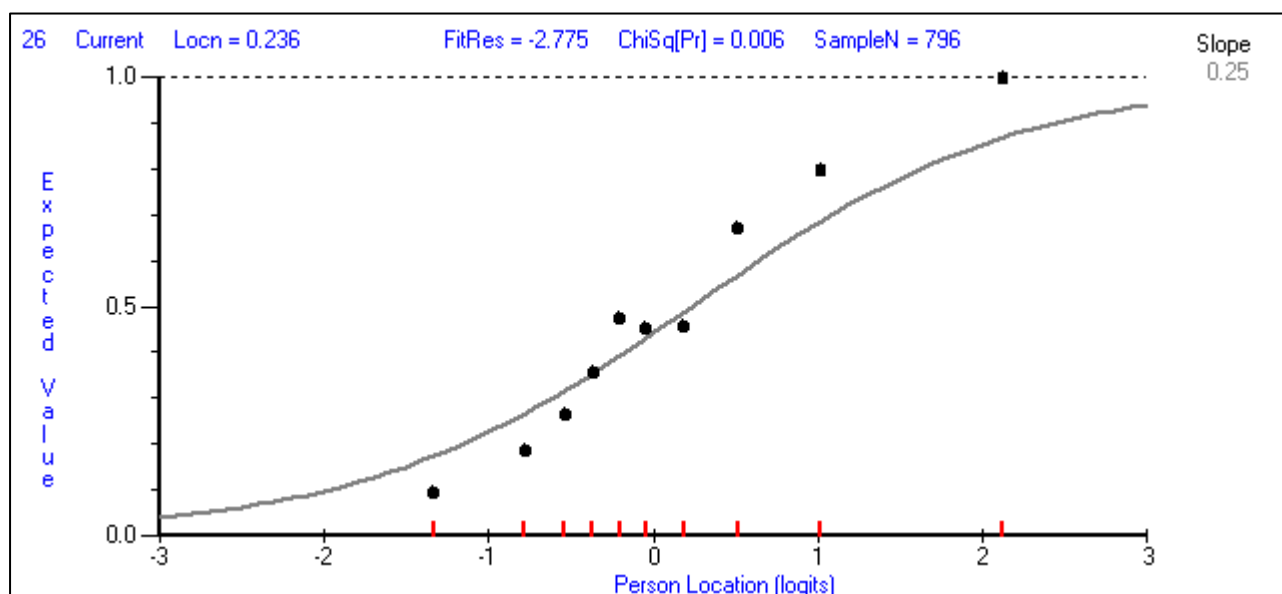


Figure 4.33.1: ICC for test-item 26

The fit residual value is -2.775 and falls just outside the normal fit residual parameters, indicating a significant deviation from the model. The negative fit residual value obtained for this test-item suggests over-discrimination. The ICC also confirms this in Figure 4.33.1, where it can be seen that responses from the lower group (those portraying poor conceptual understanding) are below what is expected by the model and those for the higher group (those portraying good conceptual understanding) falls above model expectation.

The outcome of Question 26 is that of current and voltage, where Objectives 8 and 11 are combined (Table 4.1 p.56). Question 26 deals with the effect of changing one of the resistors in a series circuit.

26) If you increase the resistance C, what happens to the brightness of bulbs A and B?

- (A) A stays the same, B dims
- (B) A dims, B stays the same
- (C) A and B increase
- (D) A and B decrease
- (E) A and B remain the same

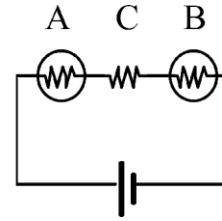


Figure 4.33.2: Test-item 26 (Correct Option: D)

This test-item determined students' conceptual understanding regarding equivalent resistance and how it affects the current in a circuit. Since the current is the same for all elements in series, the brightness of both light bulbs A and B would decrease. Forty-one per cent of the students managed to select the correct option. Option A was the most popular wrong answer, with 38% of the students making this selection. These choices indicate sequential reasoning, believing that the change occurs 'after' bulb A.

#### Question 27:

At a person location of 0 (horizontal axis) the probability of participants choosing the correct response is slightly above 0.5 (vertical axis Fig. 4.34.1), indicating that this test-item functioned well within the sample.

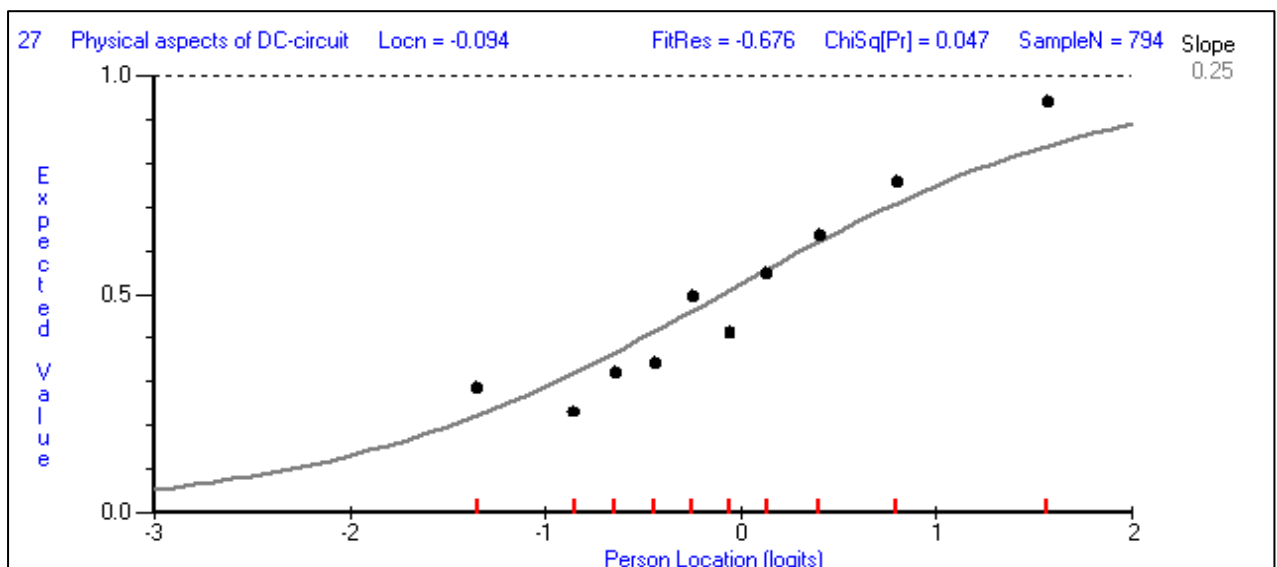


Figure 4.34.1: ICC for test-item 27

The objective of question 27 is to examine participant's ability to identify a complete circuit, consequently assessing their conceptual understanding of a short circuit (Objectives 1-3 combined, Table 4.1 p. 56). The outcome being tested is the physical aspects of a DC-electric circuit.

Forty-nine per cent (Table 4.3 p.59) of the participants could identify the correct realistic drawing of the circuit. Option C was the most popular incorrect option, where 18% of the students made this selection, not realising that it was an open circuit as the cell was connected to the glass.

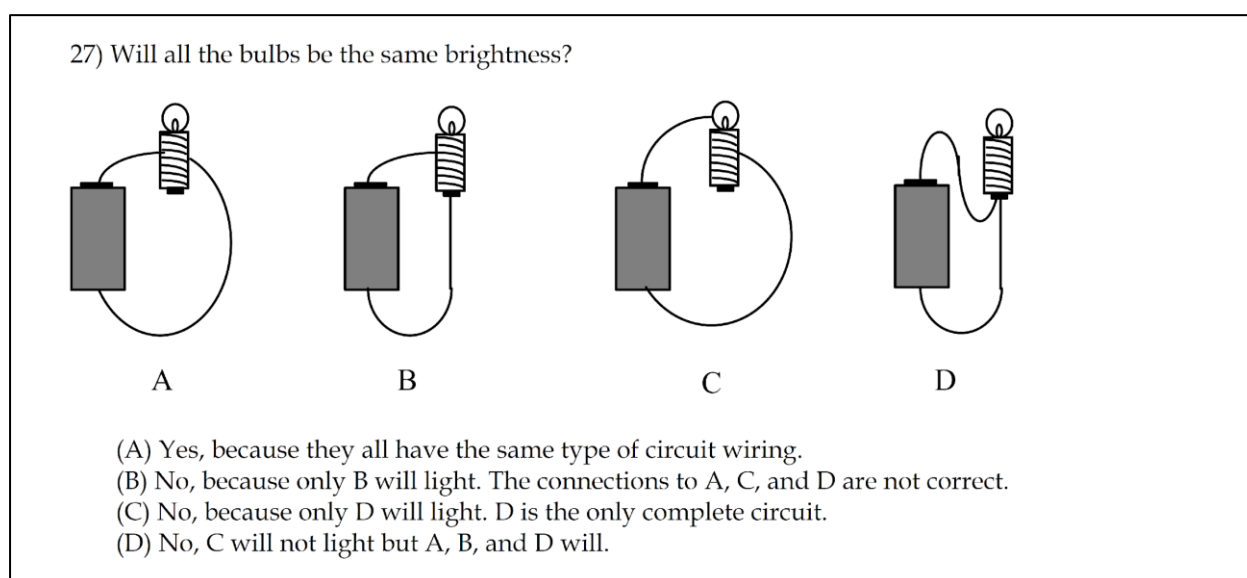


**Figure 4.34.2: Question 27 (Correct Option: B)**

The participants had difficulty identifying the correct schematic from a written description of the circuit or identifying the correct “realistic” representation of a circuit from the given schematic.

Participants considered circuits that contained shorted-out elements as working (circuits A and D) where the contacts from the cell were connected to the same point on the light bulb. Students have a weak conceptual understanding about the appropriate contacts of screw-type light bulbs.

### Question 29:

At a person location of 0 (horizontal axis) the probability of participants choosing the correct response is above 0.2 (vertical axis fig. 4.35.1), indicating that this test-item was hard and challenging.

The fit residual value is 3.442 and falls outside the normal fit residual parameters, indicating a significant deviation from the model. The positive fit residual value obtained for this test-item suggests a low level of discrimination which can also be seen in the deviation of the plot of observed group responses from the model curve. The observed response is flatter than the ICC, indicating under-discrimination. Responses from the low ability group (those portraying poor conceptual understanding) are above what is expected by the model, and those for the high (those portraying good conceptual understanding) are below model expectation.

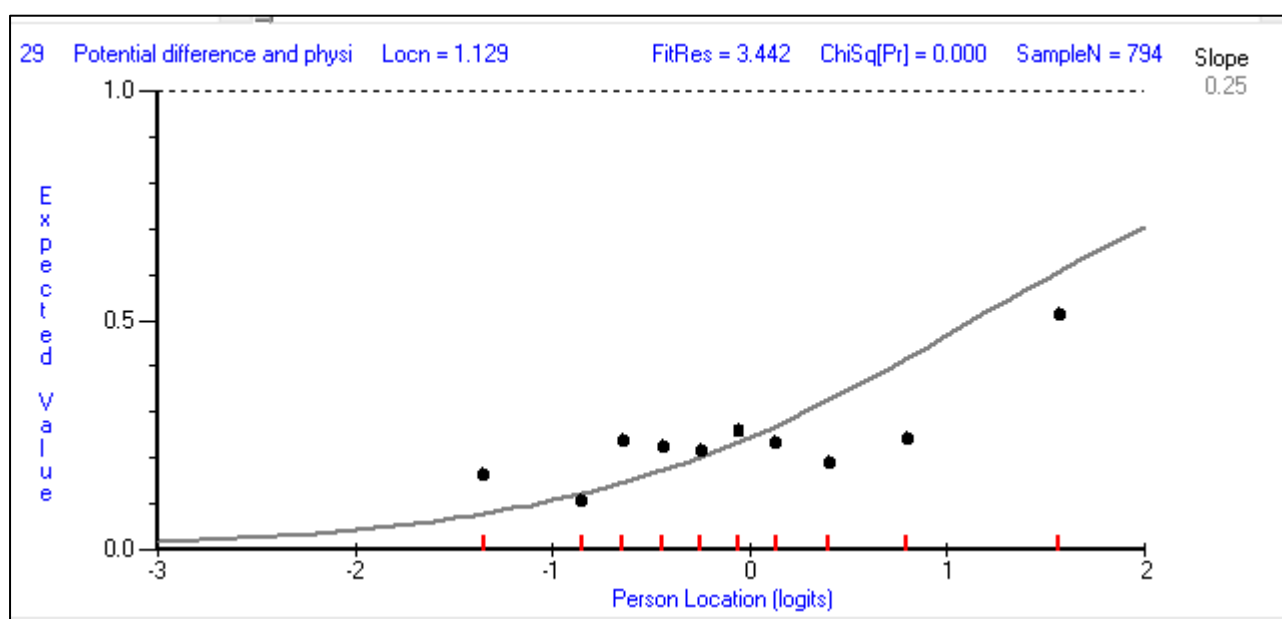


Figure 4.35.1: ICC for test-item 29

The outcome for question 29 is that of potential difference. Students need to conceptually understand the concept of potential difference and then apply their knowledge to a variety of circuits (Objective 11; Table 4.1 p.56).

Question 29 (Fig. 4.35.2) is initially a series circuit containing two light bulbs, A and B. However, as soon as the switch is closed, the circuit becomes a series/parallel combination. Participants need to conceptually understand that adding a resistor in

parallel will decrease the equivalent resistance. As a result the current will increase. Therefore bulb A will become brighter while bulb B will dim. Although the current increases in the circuit, the power  $V^2/R$  dissipated in B will now be less than before.

Only 24% per cent of the participants arrived at the correct answer (Table 4.3 p.59). Forty per cent chose option A, the most popular wrong answer, reasoning either that the cell is a constant current source or that bulb A is unaffected because the change occurs after bulb A (sequential reasoning). In both cases, local reasoning then suggests that the current will split evenly at the junction and divide between B and C, meaning that B will be dimmer than before.

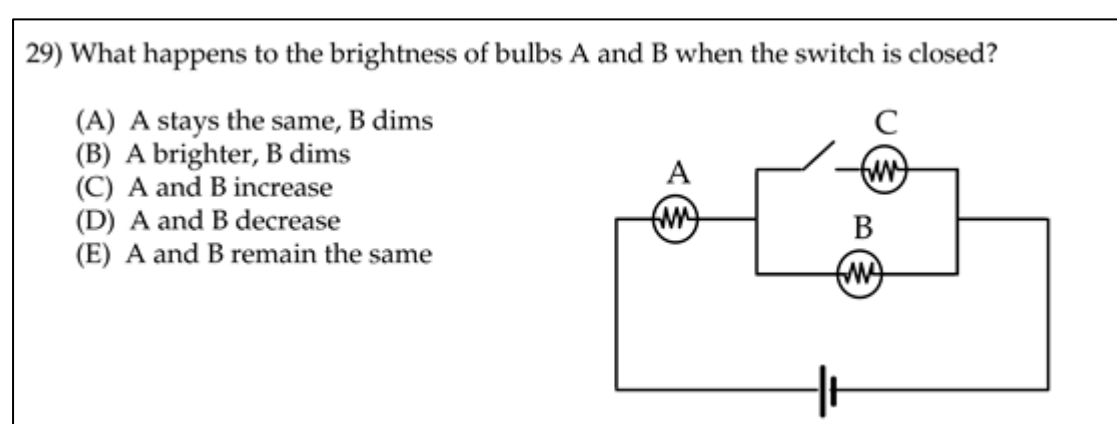


Figure 4.35.2: Test-item 29 (Correct Option: B)

### 4.5.3 Summary of students' misconceptions revealed by the test

Table 4.6 gives a descriptive summary of misconceptions associated with each test-item. The table also compares students' use of these misconceptions in the current study and an international study conducted by Engelhardt (1997).

**Table 4.6: Comparison of the average use of misconceptions in the current study and an international study**

| <b>Misconception</b>                 | <b>Question and relevant option on DIRECT</b>             | <b>AVERAGE USE SOUTH AFRICA (%) 2013</b> | <b>AVERAGE USE USA-CANADA-GERMANY (%) (Engelhardt, 1997)</b> |
|--------------------------------------|-----------------------------------------------------------|------------------------------------------|--------------------------------------------------------------|
| Battery superposition                | 3e; 12a                                                   | 23.5                                     | 27                                                           |
| Battery as a constant current source | 2c; 3b; 7c; 10c; 15a; 21e; 25c; 26a; 26b; 26e; 29a        | 25                                       | 27                                                           |
| Complete circuit                     | 9c; 9e; 18a; 18e; 27a; 27c; 27d; 29c                      | 16                                       | 6.5                                                          |
| Contacts                             | 9c; 9e; 22a; 22c; 22d; 22e; 27a; 27c; 27d                 | 14                                       | 11                                                           |
| Current consumed                     | 6a; 6b; 8a; 8b; 10c; 17c; 21b; 21c; 26a; 26b              | 21                                       | 18                                                           |
| I cause E                            | 20c                                                       | 62                                       | 63                                                           |
| Local reasoning                      | 3b; 10e; 29a                                              | 29                                       | 32                                                           |
| Equivalent resistance                | 10d; 15a                                                  | 23                                       | 24                                                           |
| Resistive Superpositioning           | 5c; 14a; 28d; 29d                                         | 20                                       | 18                                                           |
| Rule application error               | 2a; 5a; 23a                                               | 10                                       | 25                                                           |
| Sequential reasoning                 | 2c; 26a; 26b; 29a                                         | 28                                       | 26                                                           |
| Term confusion – I vs E              | 1c                                                        | 30                                       | 32                                                           |
| Term confusion – I vs R              | 23d                                                       | 34                                       | 39                                                           |
| Term confusion – I vs V              | 6a; 6b; 15a; 17e; 24a; 28a                                | 31                                       | 32                                                           |
| Topology                             | 4e; 10c                                                   | 32                                       | 35                                                           |
| Short circuit                        | 4e; 10a; 10b; 10c; 18b; 18d; 22a; 22c; 22d; 27a; 27c; 27d | 18                                       | 18                                                           |

**Engelhardt (1997)**

The SA learners' misconceptions have a mostly similar occurrence as the students in the earlier study (Engelhardt, 1997) in Germany and North American schools. There is one noticeable exception in that there is a large difference in students' conceptual understanding regarding complete circuits when comparing the two studies' results. According to the table, 16% of SA students could not identify a complete circuit compared to only 6% in the international study.

Questions 10 and 27 (Objective 1) similarly examine participants' ability to demonstrate their conceptual understanding regarding the effects of a short circuit. The table shows that 18% of SA students did not recognize short circuits in this test, indicating a weakness in the way circuits are taught in SA. It is a serious problem if first-year university students do not understand a short circuit's basic concept. Furthermore, it impacts their ability to understand more complex circuits.

The voltage objective is associated with questions 6, 15, 28, and 29. Common misconceptions that seem to relate to these questions include: *battery as a constant current source*, *term confusion* (current with voltage), *local reasoning*, and *battery superposition*. These misconceptions portray students' beliefs regarding the cell's properties and what it supplies to the circuit, with the exception of local reasoning. Similarly, these misconceptions relate to the physical aspects of the circuit and include: *topology*, *contacts*, and *term confusion* (current with resistance). Topological errors indicate that students only consider the surface features of the circuit. The contact error indicates that students do not conceptually understand how to locate the contact points on a light bulb. Term confusion (current with resistance) errors indicate that students do not conceptually understand that a resistor (including light bulbs) has an internal resistance that depends on its shape and material characteristics. Students had difficulties with the physical aspects of DC-electric circuits, displaying a weak conceptual understanding regarding the physical nature of circuit diagrams and its associated elements.

Questions 6, 15, 17, 24, and 28 reveal some misunderstanding about current and voltage. Students demonstrated either to believe that current and voltage would always occur together, or instead that current is the cause for voltage.

Questions 3 and 12 contain cells that are in series and/or parallel. Students found these test-items conceptually challenging, especially regarding the functioning of cells when connected in parallel.

Questions 4, 9, 13, 18, 22, and 27 demonstrate students' beliefs about the physical layout of an electric circuit. Questions: 4, 13, and 22, in particular require students to translate between three descriptions of circuits, namely; verbal, "realistic", and schematic. The results are shown in Table 4.7.

**Table 4.7: Participants' ability to translate between circuits presented schematically, realistically, and verbally**

|     |                                                                                                                            |
|-----|----------------------------------------------------------------------------------------------------------------------------|
| 68% | Participants cannot translate a written description of a parallel circuit into the two correct schematics. (Question 4)    |
| 13% | Participants cannot translate a “realistic” representation of a circuit into the relevant schematic circuit. (Question 13) |
| 78% | Participants cannot translate from the schematic version to a “realistic” representation of the circuit. (Question 22)     |

Although students apply different misconceptions to each test-item, they do have a tendency to apply misconceptions associated with the global objective of the particular test-item, as discussed in the next section.

#### **4.6 Chapter Summary**

Table 4.8 illustrates how the SA participants in this current study performed on each of the instructional objectives compared to those students who participated in the study conducted by Engelhardt (1997). It should however be mentioned that the sample of students that participated in the research study of Engelhardt (1997) all completed a unit on electrostatics as well as on DC-electric circuits at the university level before completing the DIRECT-Instrument, so they might have been advantaged. The average percentage correct for the SA students was obtained by adding the averages obtained for each question (Table 4.3 p.59) and dividing it with the number of questions included within that objective.

**Table 4.8: SA performance vs USA-Canada students' performance for different outcomes**

| OUTCOME                                  | OBJECTIVE  | QUESTION | AVERAGE PERCENTAGE CORRECT                                 |                                      |
|------------------------------------------|------------|----------|------------------------------------------------------------|--------------------------------------|
|                                          |            |          | SOUTH AFRICAN STUDENTS<br>(Participating in current study) | USA - CANADA-GERMANY STUDENTS (1997) |
| Physical aspects of DC-electric circuits | 1          | 10       | 48                                                         | 56                                   |
|                                          |            | 19       |                                                            |                                      |
|                                          |            | 27       |                                                            |                                      |
|                                          | 2          | 9        | 49                                                         | 54                                   |
|                                          |            | 18       |                                                            |                                      |
|                                          | 1, 2 and 3 | 27       | 50                                                         | 68                                   |
|                                          | 4          | 5        | 59                                                         | 59                                   |
|                                          |            | 14       |                                                            |                                      |
|                                          |            | 23       |                                                            |                                      |
|                                          | 5          | 4        | 48                                                         | 55                                   |
| 13                                       |            |          |                                                            |                                      |
| 22                                       |            |          |                                                            |                                      |
| Energy                                   | 6          | 2        | 48                                                         | 37                                   |
|                                          |            | 12       |                                                            |                                      |
|                                          | 7          | 3        | 56                                                         | 47                                   |
|                                          |            | 21       |                                                            |                                      |
| Current                                  | 8          | 8        | 58                                                         | 62                                   |
|                                          |            | 17       |                                                            |                                      |
|                                          | 9          | 1        | 25                                                         | 31                                   |
|                                          |            | 11       |                                                            |                                      |
|                                          |            | 20       |                                                            |                                      |
| Potential Difference                     | 10         | 7        | 61                                                         | 60                                   |
|                                          |            | 16       |                                                            |                                      |
|                                          |            | 25       |                                                            |                                      |
|                                          | 11         | 6        | 34                                                         | 37                                   |
|                                          |            | 15       |                                                            |                                      |
|                                          |            | 24       |                                                            |                                      |
|                                          |            | 28       |                                                            |                                      |
|                                          |            | 29       |                                                            |                                      |
| Potential Difference & Current combined  | 8 & 11     | 26       | 42                                                         | 45                                   |

**Engelhardt (1997)**

The results of the SA students participating in this study tend to be lower than their counterparts of other countries. The exception was for the outcome energy (Objectives 6 and 7), where the SA students performed noticeably better.

Large differences were found in Objective 1 and Objectives 1-3 combined, indicating that DC-electric circuits' physical aspects seem to have been problematic for SA students.

Specifically, the aspects related to short circuits and the identification of the location of contact points on the screw-type light bulb were problematic.

The SA students performed worst (25% correct) in Objective 9, relating to microscopic aspects of circuits which is not included in the SA curriculum. Second from last was objective 11 at 34%, concerning potential difference across parallel and series circuits.

For the remainder of the outcomes, it seems as if SA students tend to have the following misconceptions with regards to simple DC-electric circuits : sequential reasoning (related to Objectives 6 and 11; outcomes energy and voltage; Although students performed better on question 6 compared to question 11, sequential reasoning remains present), resistive superpositioning (related to objectives 11; outcomes voltage and the physical aspects of a DC-electric circuit), current consumed (related to objectives 11, 8, 1 and 7; outcomes voltage, current, the physical aspects of a DC-electric circuit and energy), misconceptions regarding contact points on a light bulb (related to objectives 1, 2 and 5; outcome the physical aspects of DC-electric circuits) and identifying a complete circuit (related to objectives 1, 2 and 3; outcome the physical aspects of DC-electric circuits).

The SA curriculum falls short on teaching the concept of short circuits and the contact points on a screw-type light bulb as well as the cells connected in parallel. Aspects that need to be emphasised within the SA curriculum would be to:

- (a) Identify a complete circuit within a diagram, both theoretically and practically;
- (b) Identify a complete circuit with cells and or light bulbs in parallel; *and*
- (c) Representing and identifying circuit components schematically and practically, showing the connection point at the tip of the screw-type bulb.

Physical Science teachers also need to pay special attention to aspects regarding the potential difference and current to avoid term confusion and misconceptions related to these outcomes.

# ***CHAPTER 5:***

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## **EXPLORING THE RELATIONSHIP BETWEEN CONTEXTUAL FACTORS AND LEARNER PERFORMANCE: Results, Analysis and Interpretation**

### **5.1 Introduction**

The purpose of this chapter is to investigate to what extent students' contextual factors can be associated with their conceptual understanding of simple DC-electric circuits. During the data collection process, the participants were required to answer ten questions eliciting personal information before completing the DIRECT-instrument's test items. These questions reveal the contextual data and will be referred to as contextual factors in the Rasch analysis.

These biographical questions range from the type of school that participants had attended, their home language, their exposure to practical work, previous performance, and their attitudes towards Physical Science as a school subject. This was done using quantitative analysis. The outcome of the analysis will be used to answer the second secondary research question:

*How do students' conceptual understanding of DC-electric circuits relate to contextual factors?*

### **5.2 The Biographical Questionnaire**

The DIRECT-instrument was used in other studies (Karpatzianis & Kriek, 2012; Zimmerman, 2015) and was considered a reliable and valid (Engelhardt & Beichner, 2004) test. However, certain test items had to be deleted from the DIRECT-instrument to fit the Rasch model (Ch. 4) to increase the test's validity for the sample in this study. The biographical questionnaire in this research study was utilised to identify contextual factors that might be related to SA students' conceptual understanding of simple DC-

electric circuits. This study did not aim at making any claims about causal relationships, but only possibilities of factors that might be worthwhile to investigate in terms of causal relationships in further research.

The biographical questionnaire (Annexure A) consisted of structured-undisguised questions, where the questions were presented in the same order and wording to all participants (Churchill, 1995, p.351). A structured-undisguised questionnaire was selected as it is quite simple to administer and to analyse. It was also easy for participants to answer as they know exactly what the researcher wanted to know (Churchill, 1995, p.351). Maree and Pietersen (2007a, p.163) also added that the advantages of this type of questionnaire included that it was easy and quick to answer and that coding and statistical analysis could easily be done.

Table 5.1 indicates how the questions within the biographical questionnaire have been grouped:

**Table 5.1: Classification and selection of questions within the biographical questionnaire**

| LEVELS OF CLASSIFICATION        | CONTEXTUAL FACTOR                                                                                              |
|---------------------------------|----------------------------------------------------------------------------------------------------------------|
| <b>(i) School level</b>         | Type of school attended                                                                                        |
| <b>(ii) Classroom level</b>     | Exposure to practical work<br>Home language                                                                    |
| <b>(iii) Student level</b>      | Final school results in:                                                                                       |
| <b>Previous performance</b>     | <ul style="list-style-type: none"> <li>• Physical Science</li> <li>• Mathematics</li> <li>• English</li> </ul> |
| <b>Personal characteristics</b> | Gender                                                                                                         |
|                                 | Attitudes towards physics                                                                                      |

Some of these contextual factors may be interrelated. For example, previous performance may be related to attitudes, while attitudes may be related to school type. Also, previous performance may influence attitudes. Exposure to practical work may be influenced by the school type, while school type may be influenced by home language,

etc. However, in the theoretical frame, the factors are grouped under the level where they are expected to have a direct influence.

In the SA public schools, science is offered only in English and Afrikaans but not in any of the nine African languages, Asian, or other home languages. Therefore, students speaking Afrikaans or English at home have an advantage in science classrooms, as they are able to receive instruction in their mother tongue. Home language directly affects the classroom environment, as instruction in the home language is regarded as important for the development of conceptual understanding.

Although the course for which students were enrolled was a contextual factor that was initially included in this study (Annexure A), it was later decided that this contextual factor made an irrelevant contribution. This study argues that the type of course enrolled for is strongly dependant on students' aptitudes and their performance in school subjects through minimum requirements for admission (Table 5.2). Each of the university programs had different admission requirements. That is why the school performance was so different per group. Table 5.2 provides information on each program's admission requirements at the time data collection took place (2013).

**Table 5.2: Admission requirements for different programs**

| Program                         | English       | Mathematics                                                                                            | Physical Science |
|---------------------------------|---------------|--------------------------------------------------------------------------------------------------------|------------------|
| <b>Engineering</b>              | 60% and above | 80% and above *<br>OR<br>70–79% provided that an 80–100% average has been obtained in Physical Science | 70% and above    |
| <b>B.Sc. Physical Science</b>   | 50% and above | 60% and above                                                                                          | 60% and above    |
| <b>B.Sc. Biological Science</b> | 50% and above | 60% and above<br>OR<br>50–59% provided that a 60–69% average has been obtained in Physical Science     | 50% and above    |
| <b>Extended program</b>         | 50% and above | 50% and above                                                                                          | 50% and above    |

*\*Percentages refer to final school results.*

Therefore, investigating the relationship between the contextual factors and student achievement was not a simple task, as the results might involve a certain degree of interdependence of the contextual factors. However, the study did not attempt to investigate the interdependence of factors. ANNEXURE F indicates how the data was inscribed within the RUMM 2020 program to undergo Rasch analysis.

### 5.3 Overview of Contextual Data

After participants had completed the biographical questionnaire, the raw data scores were captured into an *Excel*-spreadsheet. This *Excel*-spreadsheet was then used to create a table (Table 5.3 p. 124) that summarizes the profile of the majority of participants per group. The purpose of Table 5.3 was to obtain an overall picture of those contextual factors that might relate to these students' conceptual understanding of simple DC-electric circuits. Table 5.3 displays the highest incidence in each case, indicating possible connections with the participants' conceptual understanding.

At the time data collection took place (2013), the university maintained a language policy where students could choose whether they wanted to attend their course modules in English or Afrikaans; however, the extended program was offered only in English. This study assumed that each participant understood English as both the diagnostic test (Annexure B) and the biographical questionnaire (Annexure A) were set in English. Also, all the students answered their NSC examination in either Afrikaans or English. Therefore, this study did not distinguish between different language groups of the classes at university.

#### 5.3.1 Engineering group

The engineering group obtained the highest average in the DIRECT-instrument (52.6%) compared to all the other participating groups. Table 5.3 (p. 124) indicates that 47% of all the participating students who enrolled for an engineering degree obtained an average above 80% in Physical Sciences upon completing their NSC. A total of 57% obtained an average of more than 80% in Mathematics. Only 49% attended a city school, and 33% speak an African language as their home language.

The majority of the engineering students (58%) were exposed to practical work at school, working in groups. The attitude portrayed by the majority (64%) of the engineering students was that they liked physics and believed that they were good at it.

The majority of the participants in this group were males.

### **5.3.2 B.Sc. Physical Sciences group**

This group obtained a very low average (38.6%) in the DIRECT-Instrument. Only 35% of students enrolled for a B.Sc. Physical Science degree had obtained a final school average of 70%–79% for Physical Sciences. For Mathematics, equal numbers (35%) indicated that they had obtained between 60%–69% and 70%–79% for their final mark. Only 46% of the participants had been exposed to group work during their practical sessions at school. Only about one-third (32%) of this group portrayed a positive attitude towards physics, liked physics and believed that they were good at physics. Of this group, 37% of the participants attended a city school and spoke Afrikaans (39%) as their home language.

It should be noted that for some unknown reason, many of the students in this group did not indicate their gender. Therefore the majority gender within this group is not known.

### **5.3.3 B.Sc. Biological Sciences**

Table 5.3 (p.123) indicates that 47% that is almost half of all the participating students who enrolled for a degree in biological sciences, attained an average above 80% in Physical Sciences upon completing their NSC. A total of 42% attained an average between 70–79% in Mathematics. The majority of these participants attended a city school (51%) and spoke English (39%) as their home language.

Within this group, 63% of the participants were exposed to practical work at school, working in groups. Only about a third of the group (32%) indicated that they liked physics; however, they believed that they were not good at it.

The majority of those students that had enrolled for a B.Sc. Biological Sciences degree were females. This is in agreement with literature showing that females prefer biological sciences to Physical Sciences (Koerting, 2018).

#### 5.3.4 B.Sc Extended Program

Students enrolled for the B.Sc. extended program when they were not accepted for any of the other courses. Just above 40% of the students who enrolled for the B.Sc. Physical Science Extended Program obtained averages above 60% for Physical Science, Mathematics, and English in grade 12. The majority of these participants attended a city school (51%) and spoke an African language (64%) as their home language.

About 47% of these students worked in groups when doing practical work at school. It is interesting to note that although the majority (57%) of these students liked physics and regarded themselves as good at physics, they achieved the lowest average (35.6%) for the DIRECT-instrument compared to all the other participating groups. The low average is as expected, given their school performance. The surprise, however, is that this groups' beliefs about their abilities (self-efficacy) in physics almost matched that of the Engineering group. At the same time, their average performance is much lower and closer to that of the Physical Science and Biological Science groups.

Table 5.3: Typical profile of the average participant enrolled for different programs

| Program            | MOST PREVALENT DESCRIPTORS                       |                                       |                 |               |                                   |                              |                          |                                |        |                              |
|--------------------|--------------------------------------------------|---------------------------------------|-----------------|---------------|-----------------------------------|------------------------------|--------------------------|--------------------------------|--------|------------------------------|
|                    | TOTAL STUDENTS PARTICIPATING IN RESEARCH PROJECT | AVERAGE OBTAINED ON DIRECT-Instrument | SCHOOL ATTENDED | HOME LANGUAGE | GRADE 12 PHYSICAL SCIENCE AVERAGE | GRADE 12 MATHEMATICS AVERAGE | GRADE 12 ENGLISH AVERAGE | Engagement with practical work | GENDER | ATTITUDE OF STUDENTS         |
| Engineering        | 490                                              | 52.6%                                 | City school     | African       | Above 80%                         | Above 80 %                   | 70 – 79%                 | Used to work in groups         | Male   | Like physics; Good at it     |
|                    |                                                  |                                       | 49%             | 33%           | 47%                               | 57%                          | 37%                      | 58%                            | 71%    | 64%                          |
| Physical Science   | 114                                              | 38.6%                                 | City school     | Afrikaans     | 70 – 79%                          | 70 – 79% ; 60 – 69%          | 70 – 79%                 | Used to work in groups         | *      | Like physics; Good at it     |
|                    |                                                  |                                       | 37%             | 39%           | 35%                               | 35% ; 35%                    | 41%                      | 46%                            | *      | 32%                          |
| Biological Science | 142                                              | 41,4%                                 | City school     | English       | Above 80%                         | 70 – 79%                     | Above 80%                | Used to work in groups         | Female | Like physics; not good at it |
|                    |                                                  |                                       | 51%             | 39%           | 37%                               | 42%                          | 44%                      | 63%                            | 70%    | 32%                          |
| Extended Program   | 91                                               | 35.6%                                 | City school     | African       | 60 – 69%                          | 60 – 69%                     | 60 – 69%                 | Used to work in groups         | Male   | Like physics; Good at it     |
|                    |                                                  |                                       | 45%             | 64%           | 41%                               | 41%                          | 44%                      | 47%                            | 62%    | 57%                          |

\* Gender of participants was not indicated by everyone within this group.

Participants' contextual factors are complex and hard to study. Although the study did not aim to determine why students performed the way they did or claim any causality between contextual factors and conceptual understanding, it was necessary to gain information about these students' contextual circumstances to explore if students' test performance related to any of these contextual factors.

## 5.4 Reliability Analysis

After excluding four test-items (questions 14, 16, 20, and 28) from the final analysis as explained in Chapter 4, it was established that the test and the sample fit the model and the model can now be used to interpret the person factors.

Reliability is concerned with the consistency of scale, which indicates the degree of stability of the measurement, over time and over samples (Cho, 2010). As mentioned earlier, Rasch analysis employed in this study is a "psychometric technique that was developed to improve the precision with which researchers construct instruments, monitor instrument quality, and analyse respondents' performances" (Boone, 2016, p.7) through quantitative methods.

The sections that follow describe aspects that were considered to determine the biographical questionnaire's reliability so that inferences about the biographical information could be made. Aspects to check for fit would include Cronbach's coefficient alpha, overall fit discussed in Chapter 4, and unidimensionality and differential item functioning (DIF).

### 5.4.1 Cronbach's coefficient alpha

The degree of internal consistency reliability was calculated by Cronbach's coefficient alpha ( $\alpha$ ), which is most widely used for items that are not answered "right" or "wrong" but with a range of possible options (McMillan & Schumacher, 2006). The reliability coefficient ranges from 0.00 to 1, but where the scale's coefficient is high, the scale is highly reliable, and vice versa. For the most part, 0.70 to 0.90 is acceptable (McMillan & Schumacher, 2006). A Cronbach coefficient value of 0.70065 (Figure 4.8 p.71) has been obtained in this study, indicating a good model fit.

#### 5.4.2 Unidimensionality and differential Item functioning

DIF analysis is conducted by comparing the distributions of individual scores combined by class interval mean scores between options within each contextual factor (e.g. type of school attended, gender, exposure to practical work, etc.) for each item, using ANOVA.

Studies have indicated that a good conceptual understanding of DC-electric circuits depends on the degree of experience (both theoretical and practical) students had with electric circuits in secondary schooling and learner motivation and attitudes towards Physical Science (Sangam & Jesiek, 2012). Several research studies over the years (Franke & Bogner, 2011; Kahle & Meece, 1994; Lin et al., 2016; Mason, Boldrin, & Zurlo, 2006) have also flagged gender as a significant factor relating to academic performance. Other factors associated with the quality of education and conceptual understanding include the type of school students attend (Du Plessis, 2014) and students' home language vs their medium of instruction (Gudula, 2017; Probyn, 2004). Thus, DIF due to these variables (exposure to practical work, attitudes, gender, type of school, and language) might be expected. However, the absence of DIF does not reduce instrument discrimination. For this reason, averages for the different contextual factors are compared to determine if the item is measuring the same way for all participants.

Figure 5.1 illustrates the analysis of variance (ANOVA) output and the mean score obtained for “school type” the first contextual factor used within this study as an example. The ANOVA is a parametric technique used to measure the variance both within and between different groups within a sample (Cavanagh et al. 2005). Therefore, the ANOVA was used to see if there is a meaningful difference in the groups' performance identified within each contextual factor; that would mean that the factor is important in predicting performance in the test. ANOVA can test for the significance of differences in the means for more than two groups and more than one independent variable.

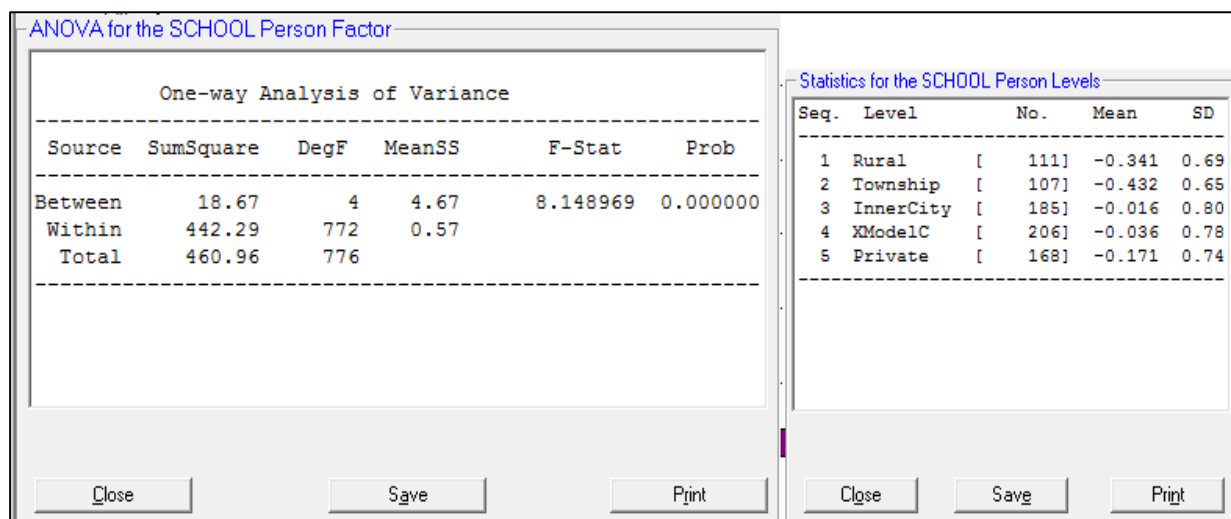


Figure 5.1: ANOVA and Mean person locations for the SCHOOL contextual factor

The RUMM 2020 software-generated ANOVAs and statistics for all contextual factors included in this study. However, to display these values in a more organised fashion Table 5.4 has been created, which includes the F-statistic values and the p-values for each contextual factor.

Table 5.4: Summary of F-values and p-values of all contextual factors

| Contextual factor          | F-value   | Probability |
|----------------------------|-----------|-------------|
| Type of School Attended    | 12.014690 | 0.000000    |
| Physical Science Average   | 28.514690 | 0.000000    |
| Mathematics Average        | 32.687760 | 0.000012    |
| English Average            | 12.686430 | 0.000020    |
| Home Language              | 23.456690 | 0.000000    |
| Exposure to practical work | 1.2061070 | 0.306731    |
| Gender                     | 56.261540 | 0.000000    |
| Attitudes towards Physics  | 20.627780 | 0.000020    |

The F-statistic value must be used in combination with the p-value when deciding if the overall results are significant. A large F-statistic value and a small p-value ( $<0.05$ ) indicate a significant difference, indicating a relation between that specific contextual factor and the students' conceptual understanding of DC-electric circuits. A p-value that

is greater than 0.05 indicates no significant difference in responses from the different groups. In other words, the null hypothesis that there is no difference between the participating groups can be accepted if  $p > 0.05$ . Contextual factors that indicated a relation to conceptual understanding are gender; Mathematics average; Physical Science average, home language, students' attitudes towards physics, English average, and the type of school students attended. The results indicate that only one factor, exposure to practical work, is not significant and not related to conceptual understanding of DC-electric circuits, as the p-value is greater than 0.05.

The analysis indicated that exposure to practical work shows no significant relationship with students' conceptual understanding of simple DC-electric circuits as measured by the DIRECT-instrument. This is the only contextual factor for which no significant difference existed between groups' performances and is discussed in more detail later in this section.

The performance of learners attending inner-city and ex-model C schools was quite similar. Therefore, a separate comparison was made between students who attended an ex-Model C school (mean location = -0.035; SD = 0.79) to those who have attended an inner-city school (mean location = -0.015; SD = 0.82). An ANOVA revealed no significant differences in conceptual understanding of students attending an inner-city school, compared to those who attended an ex-Model C school ( $F = 0.014924$  and  $p = 0.999561$ ). The spread of responses was mostly similar, and they were viewed as one group called city schools from here onwards. This group of participants achieved the highest results, and one may, therefore, assume that they have a better conceptual understanding of simple DC-electric circuits.

#### **5.4.3 Person frequency distribution and analysis**

Within the Rasch model framework, the person location distribution can be used as a strategy for examining differences between all levels of conceptual understanding within a particular contextual factor. DIF-outputs were obtained for each item to investigate contextual factor bias per item. Significant results indicated the presence of DIF. The Person Frequency Distribution Curve for each contextual factor considered in this study is analysed and explained in the following sections.

The Person Frequency Distribution graphs indicate the degree of comparability between the different groups measured within a contextual factor and the number of students participating within that group. The horizontal axis of these graphs is similar to the person axis of the item map (Fig 4.10 p.74). The person location is a measurement of a participants' ability. A person with an average ability (0.00 person location) has a 50% chance of getting the item at the 0.00 item location correct.

Each bar indicates the frequency of participants at a specific location, which can be read off on the vertical axis, i.e. a frequency of 50 indicates 50 participants. The person location of the students is represented on the horizontal axis from a low ability (to the left) to a high ability (to the right). Each Person Frequency Distribution graph indicates the mean and the standard deviation (SD) value for each contextual factor in the top left corner. In the section below each of the contextual factors will be discussed.

(i) Type of School

Figure 5.2.1 indicates that there are four independent variables, i.e. groups being tested, namely students that attended rural schools (blue), township schools (red), city schools (purple), and private schools (green).

Figure 5.2.1 indicates the item mean as 0, automatically set by RUMM 2020. The 0 person location, as indicated on the horizontal axis, is where the average participant has a 50% chance to provide the correct answer for the test-item at the 0.0 item location. Participants to the left from the 0 location experienced the test-items to be difficult, whereas those to the right from the 0 location found it to be less challenging. The means of all four school types are slightly below zero.

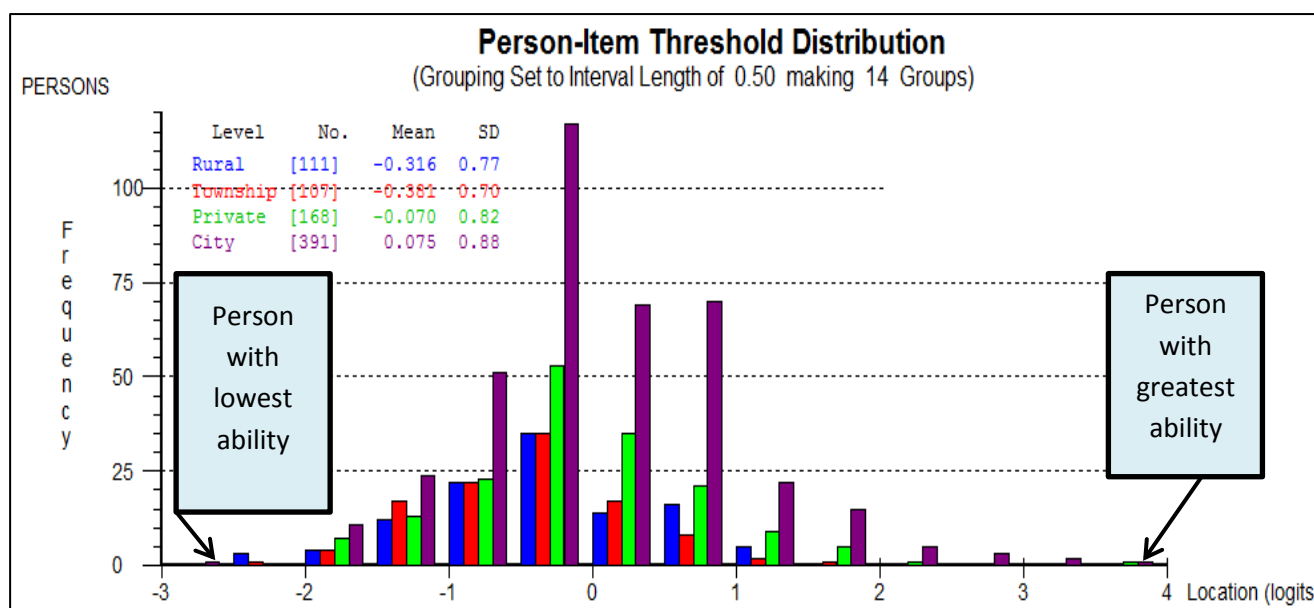


Figure 5.2.1: Person Frequency Distribution Graph - Type of school attended

Participants coming from city schools (mean location = 0.075; SD = 0.88) and private schools (mean location = - 0.070; SD = 0.82) performed better compared to participants from township schools (mean location = -0.381; SD = 0.70) and rural schools (mean location = - 0.316; SD = 0.77). Participants from city schools experienced the DIRECT-instrument to be less challenging, compared to those students that attended private schools, rural schools as well as township schools.

This study intended to explore whether these factors relate to performance and not to explain the reason for this relation. However, one might speculate that those participants that attended township and rural schools might not have performed well on the DIRECT-instrument due to:

- a) Lack of necessary resources,
- b) Inadequately trained teachers (Du Plessis; 2014), *and also*
- c) General socio-economic factors.

Du Plessis (2014) also points out that rural and township schools are characterised by various factors that negatively influence the quality of education. This appears to be so much more pronounced in rural schools where they are remote and in poorly developed communities. The socio-economic realities of rural areas put learners in rural schools at a great disadvantage.

(ii) Physical Science Performance

The results represented in Figure 5.2 are as expected: Those participants that achieved a Level 7 (80% - 100%) and Level 6 (70% - 79%) in their final Grade 12 Physical Sciences exam illustrated a better performance in the DIRECT-instrument. Participants achieving a Level 7 scored a mean location value of 0.166 and an SD-value of 0.82. Those participants who indicated to have achieved a Level 3 (40%–49%) in their matric year displayed the weakest performance in the DIRECT-instrument. Only the Level 7 participants achieved a positive mean person location (0.166). Participants achieving a Level 6 (-0.265), Level 5 (-0.476), Level 4 (-0.539) as well as participants achieving a Level 3 (-0.746) had a mean person location below zero, which means they found the DIRECT-instrument challenging.

These results are in accordance with the literature, as high school grades, in general, tend to be a very good predictor of success at the tertiary level (Geiser & Santelices, 2007; Hodara & Lewis, 2017).

(iii) Mathematics Performance

Figure 5.2.3 displays the result of the ANOVA that was expected. The analysis shows that mathematical achievement at the school level can be used as a predictor for achievement in the DIRECT-instrument. Participants that achieved a Level 7 (80%–100%) in their final Grade 12 Mathematics exam performed best in the DIRECT-instrument, achieving a Level 7 with a mean location value of 0.149 and an SD-value of 0.78. Those participants who indicated to have achieved a Level 4 (50%–59%) in their matric year displayed the weakest performance in the DIRECT-instrument (mean location = -0.623; SD = 0.59).

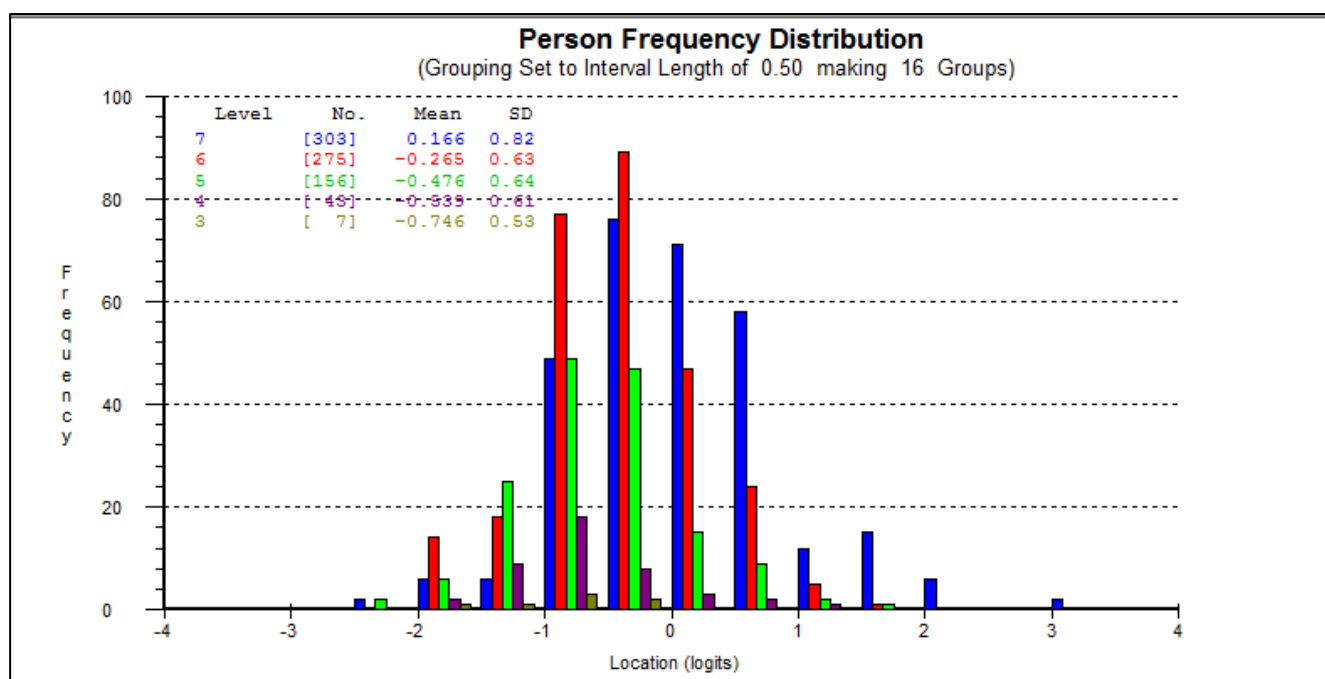


Figure 5.2.2: Person Frequency Distribution Curve - Physical Science Average

These results are in accordance with the literature, as high school grades, in general, tend to be a very good predictor of success at the tertiary level (Geiser & Santelices, 2007; Hodara & Lewis, 2017).

### (iii) Mathematics Performance

Figure 5.2.3 displays the result of the ANOVA that was expected. The analysis shows that mathematical achievement at the school level can be used as a predictor for achievement in the DIRECT-instrument. Participants that achieved a Level 7 (80%–100%) in their final Grade 12 Mathematics exam performed best in the DIRECT-instrument, achieving a Level 7 with a mean location value of 0.149 and an SD-value of 0.78. Those participants who indicated to have achieved a Level 4 (50%–59%) in their matric year displayed the weakest performance in the DIRECT-instrument (mean location = -0.623; SD = 0.59).

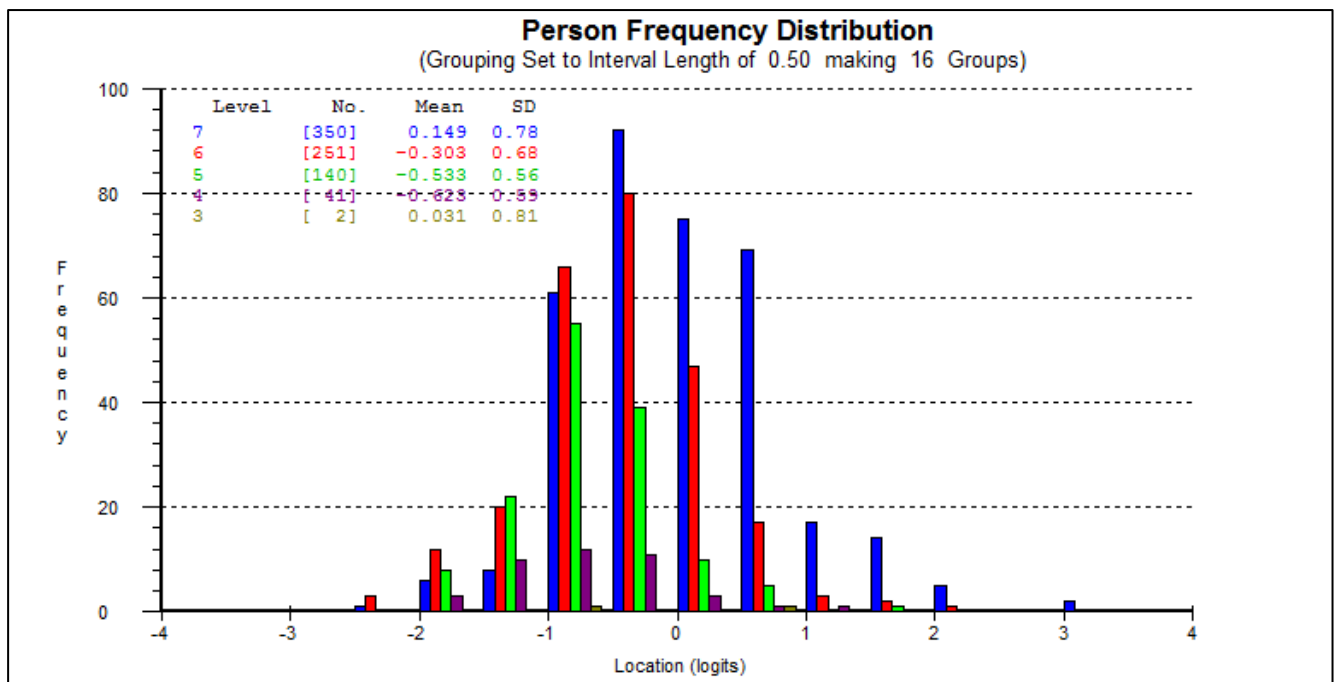


Figure 5.2.3 Person Frequency Distribution Curve - Mathematics Average

Only the Level 7 participants achieved a positive mean person location (0.149). Participants achieving a Level 6 (-0.303), Level 5(-0.533), Level 4(-0.623) as well as participants achieving a Level 3 (-0.031) have a mean person location below zero, which means they found the DIRECT-instrument challenging.

#### (iv) English Performance

It was clear from the results that participants achieving at Level 7 (above 80%) in their matric year performed the best in the DIRECT-instrument, indicating a better conceptual understanding of simple DC-electric circuits. The sample of participants who achieved a Level 4 (50% - 59%) in their NSC for English had the lowest average (mean location = -0.593; SD = 0.49). Figure 5.2.4 indicates a general decrease in the mean location as the level in English performance decreases

Only Level 7 participants achieved a positive mean person location (0.088). Participants achieving a Level 6 (-0.156), Level 5 (-0.343), Level 4 (-0.593), as well as participants achieving a Level 3 (-0.263) had a mean person location below zero, which means they found the DIRECT-instrument challenging.

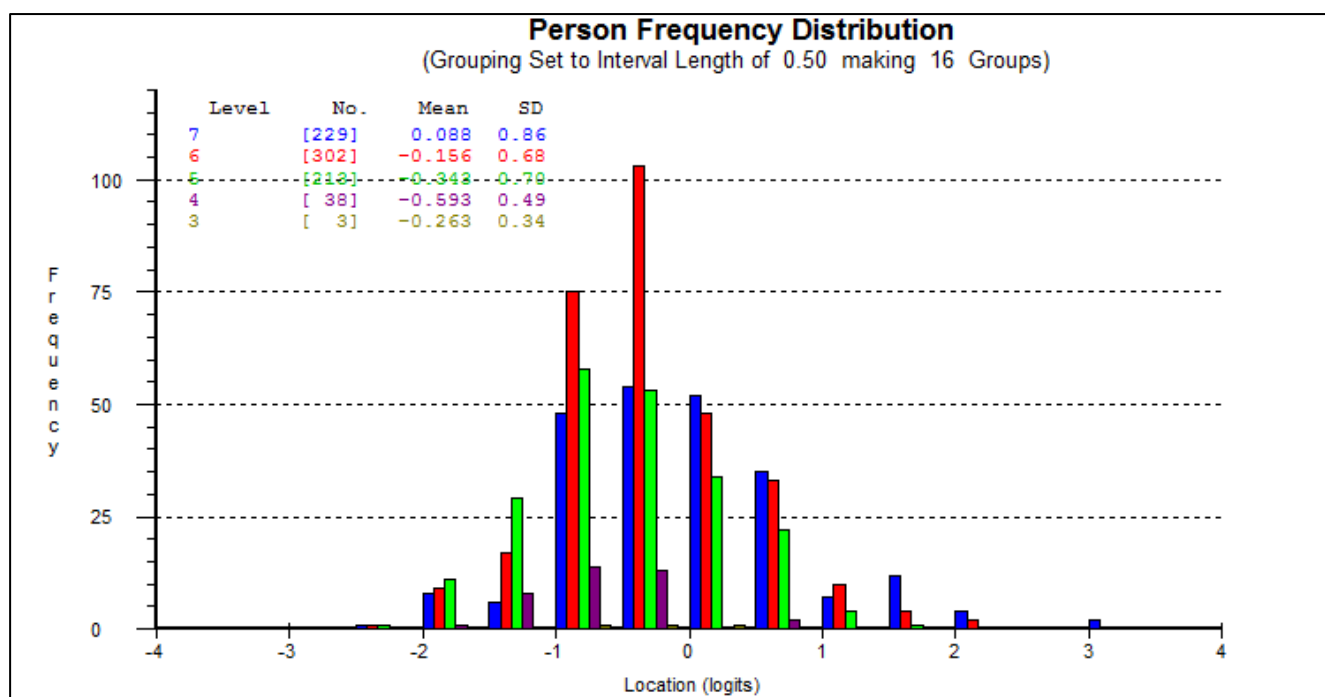


Figure 5.2.4: Person Frequency Distribution Curve - English Average

Linguistic ability may also provide more insights into students' conceptual understanding of simple DC-electric circuits. Language and thinking are key aspects that are associated with gaining insight into physics and into problems that learners have to solve in the classroom. Since learners come to school with informal ways of talking, teachers are required to adapt their classroom practices from informal spoken and written language to a more formal language to promote conceptual understanding of scientific phenomena (Setati et al., 2002).

(v) Engagement with practical work

The ANOVA revealed no significant difference in performance between participants who made use of apparatus in group work and those who were exposed to other methods of addressing practical work (Table 5.4 p. 126). When completing the biographical questionnaire, participants had the opportunity to select any one of the following options in response to the question relating to practical work (Question number 8; Annexure A): (a) Group work, (b) Demonstrations, (c) Teacher gave a reading from a book, (d) Travelling laboratory visited the school, and (e) Students visited another school/institution. In a SA setting *group work* means doing experiments where a group of

students work together to experiment and not merely fill in the worksheet in groups sitting together.

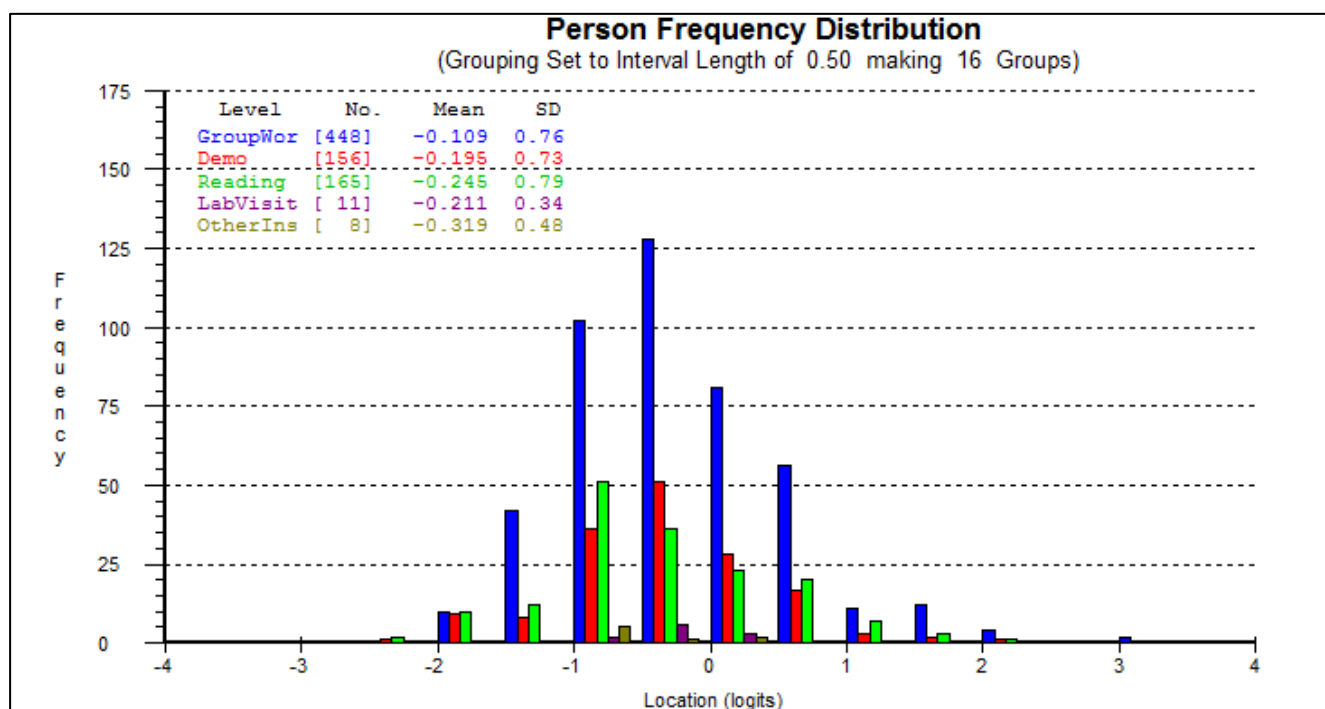


Figure 5.2.5: Person Frequency Distribution Curve - Engagement with practical work

Although participants who were exposed to practical group work seemed to perform better in the test, the ANOVA indicated no significant difference in performance results.

Surprisingly, participants not being exposed to using apparatus in group work for practicals do not seem to have been disadvantaged in their performance when completing the DIRECT-Instrument.

These results are surprising as it contradicts the expectations that working in small groups and building their own circuits would contribute to participants' conceptual understanding of electricity and electric circuits. This result brings scope for new and further investigation. The use of apparatus (even just partially) in conducting science experiments is a process associated with the development of cognitive and psycho motor skills, which facilitates the logical process of education (Michaelides, 2003). It should be noted that this study accepts that the phrases "*use of apparatus*" and "*working in groups*" imply the same thing, as the option (Option A) was: "*Learners worked in small groups to build circuits*" (ANNEXURE A). Collective knowledge construction is a process where people working in small groups, create new knowledge and new content collaboratively

(Cress & Kimmerle, 2018). The underlying idea is that learning is a social and collective activity rather than a solitary one (Lee., et al 2006). Collective knowledge construction is based on:

- (1) Knowledge that people introduce into the shared process on the basis of their own individual prior knowledge and their personal expertise, *as well as*
- (2) Knowledge that has previously been shared in the group.

It was therefore expected that practical group work would relate to participant performance rather significantly.

(vi) Gender

Figure 5.2.8 indicates that the males displayed a better conceptual understanding of simple DC-circuits than the females that participated in this study. The males (mean = 0.02 and SD = 0.8) performed better on the DIRECT-Instrument compared to the females (mean = -0.396 and SD = 0.59). Only the male participants achieved a positive mean person location (0.020). Female participants have a mean person location below zero (-0.396), which means they found the DIRECT-Instrument challenging.

The sample consists of much more males compared to females. Within this study 58.4% of the participants were male, 35.9% were female and 5.7% of the participants did not indicate their gender when completing Annexure A. The majority of the engineering students that participated in this study were males (Table 5.3 p.124) while the majority of those who enrolled for Biological sciences were female. However, gender and personal interest remain a complex issue and does not fall within the scope of this study.

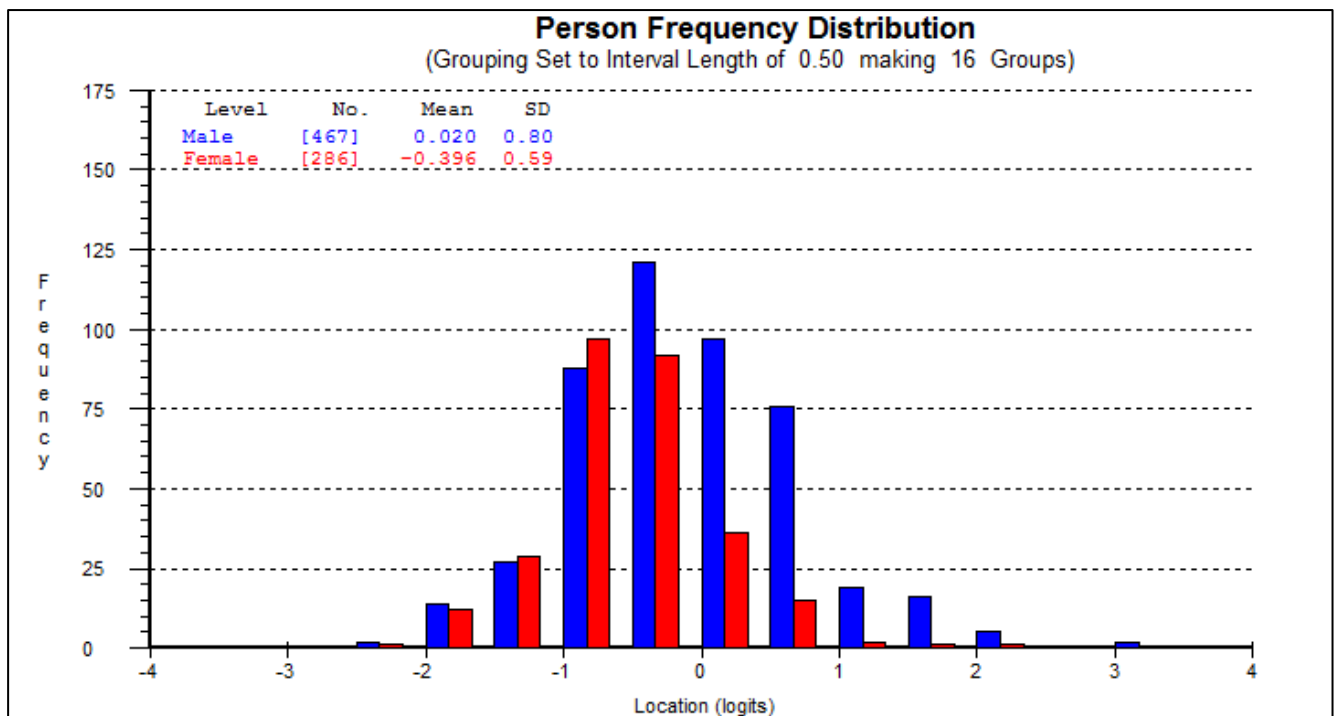


Figure 5.2.6: Person Frequency Distribution Curve – Gender

Mason et al. (2006) proposed that gender and grade level can significantly influence students' epistemology, thinking that boys display interest in more abstract concepts than girls, especially in the lower grades, which may influence preferred study fields. Franke and Bogner (2011) also point out that in later years, as boys and girls develop, young women often retain scientific concepts of molecular biology better in the long term, whereas boys can only do so for a shorter period. This might explain why more females are interested in pursuing study fields related to biological sciences than boys, who might be more interested in physical or engineering sciences (Table 5.3 p. 124).

(vii) Personal attitudes regarding Physical Science

Another contextual factor that had a significant difference in student performance in the DIRECT-instrument was students' attitudes towards the subject of Physical Science.

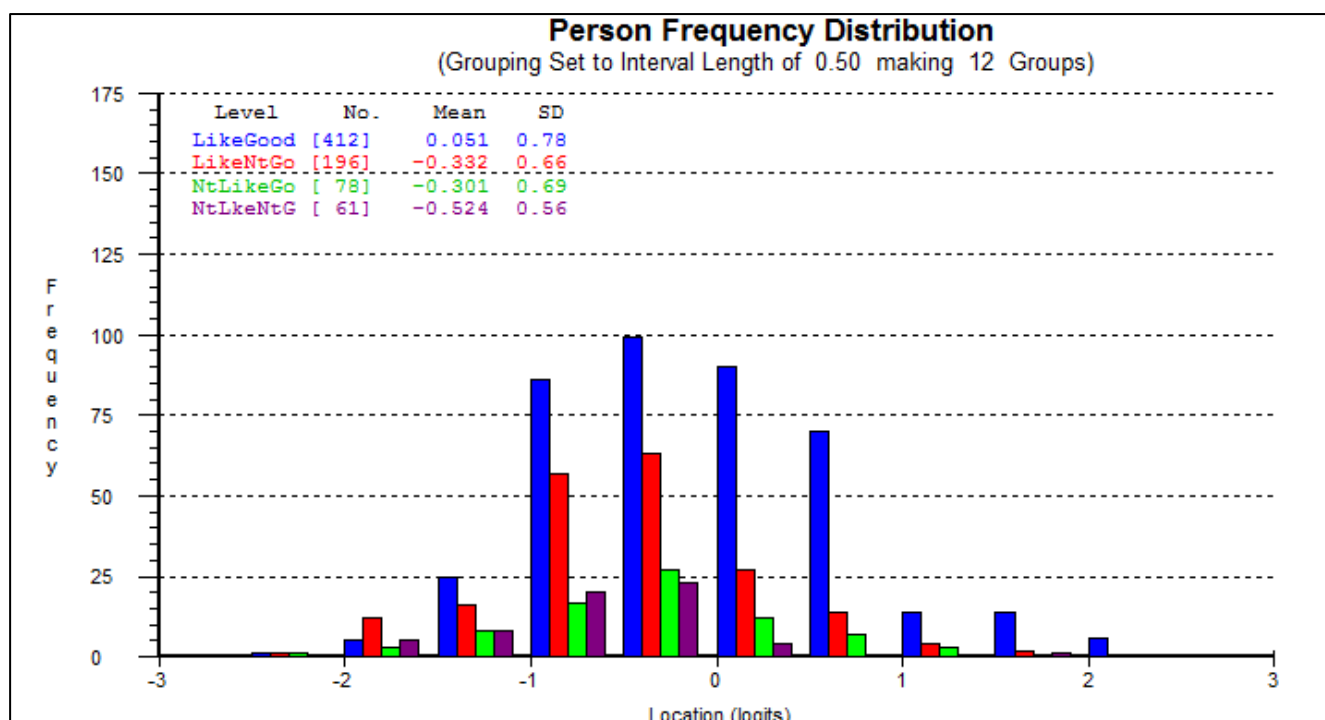


Figure 5.2.7: Person Frequency Distribution Curve – Attitudes Towards Physics

It is no surprise that students who like Physics and who regard themselves as good in Physics performed better (mean = 0.051 and SD = 0.78). Participants who do not like Physics and who think that they are not good at it (purple bars) performed the worst (mean = -0.524; SD = 0.56) in the DIRECT-instrument. It is also interesting to point out that in the biological sciences, 32% (Table 5.3, p. 123), of participants hold such negative attitudes towards Physics, while at the same time, 70% of the students in this group are females. This seems to indicate that there are more negative attitudes amongst females in this group. However, gender and personal interest remain a complex issue and do not fall within this study's scope.

#### (viii) Home Language

Afrikaans speaking students (purple bars) displayed the best test performance in the DIRECT-instrument (mean location = 0.181; SD = 0.82). Students speaking any one of the nine African languages (277 students) in SA as their home language formed the largest group (blue bars), yet they displayed the weakest performance in the DIRECT-instrument (mean = -0.413; SD = 0.64). A possible explanation would be that in SA, government schools, science is offered in either English or Afrikaans. Therefore, learners

speaking African languages at home attend science classes in a second language; usually English, and are consequently at a disadvantage to develop conceptual understanding. In the classroom, learners speaking an African language as their home language are all at a disadvantage as English is the language of instruction. At student level, many African learners may also have a disadvantaged background where many parents are illiterate due to our country's history.

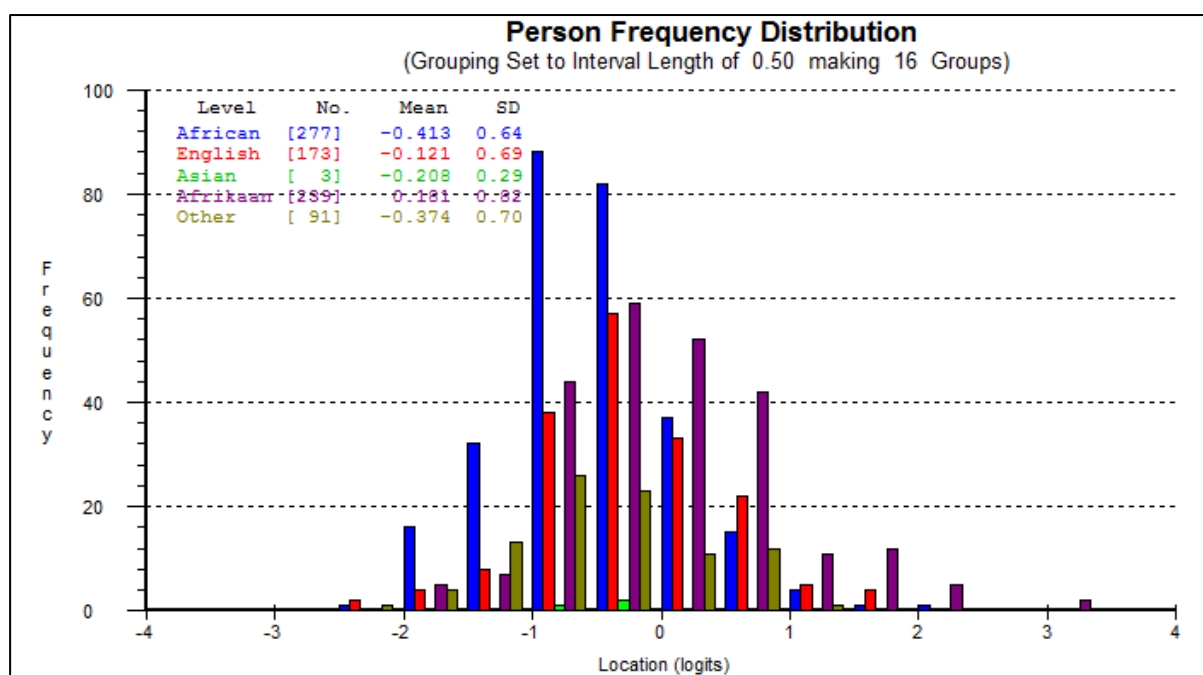


Figure 5.2.8: Person Frequency Distribution Curve - Home language

From a social constructivist perspective, home language plays an important role in the expression of understanding and concept development of scientific concepts and phenomena as scientific meaning is constructed through teachers and learners' social practices (Fox, 2001). Rollnick (2000) believes that in order to conceptually understand science learning a new language (English) is a necessity. Learners studying science in a second language face two challenges simultaneously: studying the language of teaching and learning itself and learning science in their classroom. In SA language proficiency is a strong factor influencing science achievement (Howie et al., 2008), since most students study science in a second or even third language.

## 5.5 Chapter Summary

Research has recognized and acknowledged that there are many factors influencing student achievement in Physical Science (Cress & Kimmerle, 2018; Fox, 2001; Francke & Bogner, 2011; Howie et al., 2008; Hodara & Lewis, 2017; Mason et al., 2006; Rollnick, 2000; Sangam & Jesiek, 2012). According to the conceptual framework proposed in this study (Chapter 2), contextual factors operate at the following levels (Table 5.1):

- (i) School level: (Type of school students attended);
- (ii) Classroom level: (Engagement with practical work and home language of learners);
- (iii) Student level: Previous performance of Physical Science, Mathematics, and English; Gender and attitudes towards Physical Science).

Although all three classification levels of the contextual factors (school level, classroom level, and student level) have an independent relation with student outcomes, they also have a combined effect on each other and student outcomes (Fig. 5.3). The school context (i.e. whether students attended city schools, private schools, township schools, or rural schools) would inform the classroom context (i.e. what language of instruction is used – is it the same as the students' home language; are they exposed to practical work) and the classroom context, in turn, would affect students' personal characteristics (i.e. what attitudes or beliefs do they foster about Physical Science and how it impacts on their subject marks). These three levels (school, classroom, and student) did affect their performance on the DIRECT-instrument. Therefore, it can be concluded that these factors also affect the level of their conceptual understanding of simple DC-electric circuits.

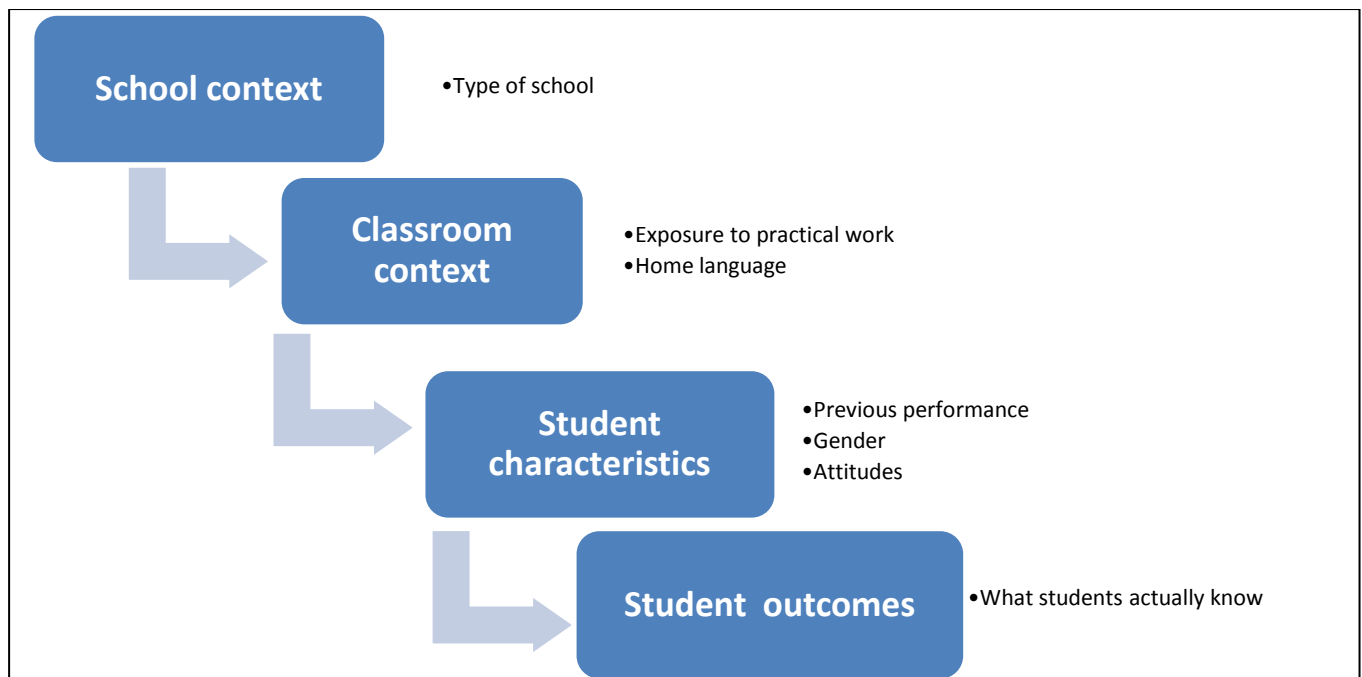


**Figure 5.3: Learning contexts and student outcomes**

The model presented in Figure 5.3 is based on the conceptual frame, indicating how the school, classroom, and student factors promote students' conceptual understanding.

Educational outcomes regarding *electricity and electric circuits* (i.e. physical aspects of DC-electric circuits, current, energy, and potential difference) have been the focus of many educational research studies as it can easily be assessed utilising standardised performance tests. In this study, the DIRECT-instrument was used. The results of the study can be used to motivate the need to develop educational contexts.

Since the data and the sample fit the Rasch model, valid inferences were made from the results. The unidimensionality and differential item functioning support the validity of this study. This study's findings indicated that conceptual understanding is associated with most of the contextual factors included in the conceptual framework. The exception was students' exposure to practical work. Although the factors in question relate to performance, this study does not claim causality. This study aimed not to search for explanations; however, there is scope for further research to explore explanations of how these contextual factors are associated with conceptual understanding.

These contextual factors include:

(i) *Type of schools students attend*

Participants attending city schools and private schools performed better in the DIRECT-instrument than participants attending rural and township schools.

(ii) *Physical Science achievement*

A better Physical Science achievement during secondary schooling corresponds to a better conceptual understanding.

(iii) *Mathematics achievement*

A greater mathematical skill during secondary schooling corresponds to a better conceptual understanding.

(iv) *Achievement in English*

Participants who displayed better English performance during secondary schooling also achieved a better performance in the DIRECT-instrument, indicating a better conceptual understanding of DC-electric circuits.

(v) *Home language*

Students speaking any one of the nine official African languages and Asian or other languages at home in SA tended to perform worse on the DIRECT-instrument than those speaking either English or Afrikaans as their home language. Therefore, there is a significant effect for learners speaking African languages at home at classroom level, compared to those speaking either English or Afrikaans as their home language.

(vi) *Gender*

The males outperformed females. The majority of participants were males who enjoyed Physical Science as a subject in general and believed that they were very good at it. They also seemed to have a better mathematical ability. Although the sample of females (35,9%) participating in this study was smaller compared to that of the males (58,4% Fig. 5.2.6 p.57), it was interesting to find that the majority of females preferred a

career field in biological sciences, and they also tended to have negative attitudes towards physics in general.

(vii) *Attitudes towards Physical Science*

Participants believed they were good at Physics and liked the subject performed better on the DIRECT-instrument than those who did not.

(viii) *Engagement with practical work*

Although the majority of participants indicated they have worked in small groups to build electric circuits at school, it seemed that it made no significant difference in their conceptual understanding of simple DC-electric circuits.

Contextual factors that relate to students' conceptual understanding of Physical Science have been explored and the results support existing literature, except for the exposure of practical work. These contextual factors have been examined and studied through person frequency distribution curves that have been generated by the RUMM 2020 software as set out in the previous sections. Students' conceptual understanding is shaped by their school environment, classroom environment, as well as their characteristics.

# CHAPTER 6:

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## CONCLUSION

### 6.1 Introduction

Although the DIRECT-instrument provides a quantitative view of students' conceptual understanding of simple DC-electric circuits, it does not consider each student's contextual factors, which could have possibly contributed to variations in performance. Humans vary in a considerable amount of ways regarding their social and educational, cultural, historic, and demographic contexts. These diversities may account for the discovered variations in science performance among first-year university students in SA.

Research in science education has been dominated by the idea that students hold misconceptions that are persistent and resistant to change. Misconceptions have been variously labelled as alternative conceptions, naïve conceptions, or pre-conceptions (Driver, 1989; Shipstone, 1985). As we make sense of the world around us, non-scientific ideas may easily take form in the minds of especially young children. As a result such incorrect associations may develop into a weak conceptual understanding of a topic being studied.

The study set out to explore the nature of first-year university students' conceptual understanding of simple DC-electric circuits, considering those contextual factors that make up part of their everyday context. The study has also sought to understand whether these contextual factors relate to the participants' way of thinking of simple DC-electric circuits to validate the SA context's diagnostic tool.

Furthermore, the study sought to answer the following research question:

Primary research question:

*What is the nature of conceptual understanding about DC-electric circuits amongst students entering a first-year physics module at a South African University and how does this understanding relate to contextual factors?*

Secondary research question:

- (i) *How can students' understanding of DC-electric circuits be characterised in terms of critical concepts within the topic?*
- (ii) *How does students' conceptual understanding of DC-electric circuits relate to contextual factors?*

The previous two chapters (chapters 4 and 5) have presented, analysed, and discussed the data generated. As a result, this chapter presents the summary, main conclusions, and recommendations derived from the data analysis and discussions. Based on the results discussed in the previous two chapters and the conclusions of this study, noteworthy recommendations are made.

In this final chapter, the outcome of the research is given by answering the research questions, followed by reflections and discussions on the conceptual framework. This chapter also emphasises how the discoveries of this study may contribute to the body of knowledge in the domain of science education. Recommendations for further research are presented ending with conclusions based on the results obtained.

## **6.2 Overview of the Study**

This study sought to explore the nature of first-year university students' conceptual understanding of simple DC-electric circuits and how their understanding relates to contextual factors. The topic of *electricity and electric circuits* was investigated as it is a problematic topic reported in the international literature (Bernhardt & Carstensen, 2015; Dupin & Joshua, 1987; Engelhardt & Beichner, 2003; Fler, 1994; Gunstone et al., 2009; Hart, 2008; Karpatzianis & Kriek, 2012) as well as in the SA literature (DoBE, 2013; DoBE, 2019; Gaigher, 2014; Khumalo & Naidoo, 1996; Moodley & Gaigher, 2017; Zimmerman, 2015). The study assessed the quality of students' understanding of circuits at the time when they enter university. This knowledge can be used as a barometer of what was learned and retained during their school career, thereby probing the effectiveness of teaching electric circuits in SA schools.

The topic of *electricity and electric circuits* forms a key part of the SA curriculum throughout the FET-phase. The content covered during Grades 10 and 11 is also

indirectly examinable in the final matric exam because understanding concepts of current, voltage, resistance, series, and parallel connections would form the backbone of any electric circuit question. A review of science education literature reveals that the topic of *electricity and electric circuits* is a common site for misconceptions, both in teachers and students (Engelhardt & Beichner, 2004; Loughran et al., 2006; Mulhall et al., 2001; Pesman & Eryilmaz, 2010; Summers et al., 1998; Wainwright, 2007; Zimmerman, 2015). Apart from misconceptions, literature also shows that many students can solve circuit problems algebraically while unable to answer questions based on conceptual understanding (DoBE, 2011; Gaigher et al., 2007). The DIRECT-instrument was designed specifically to test conceptual understanding (Engelhardt, 1997).

Participants that entered a first-year university course containing a physics module were selected for the study. The study focused on exploring participants' conceptual knowledge of basic DC-electric circuits rather than algebraic calculations involving components in a DC-electric circuit. Furthermore, to better understand the context of student achievement on the DIRECT-instrument, the current research considered some contextual factors that might relate to conceptual understanding. These contextual factors include:

(i) *The type of school participants attended.*

There are various schooling options in SA, from state-funded schools to private and international ones, each providing its own standard of education. In SA, education is compulsory from Grade 1 (age 6) to Grade 9 (age 15).

Participants with different schooling backgrounds performed differently in the diagnostic tool used. This could have been indicative of a good conceptual understanding regarding simple DC-electric circuits in students coming from certain schools and very poor conceptual understanding with participants having some deeply rooted misconceptions in others.

(ii) *Students' home language.*

There is currently much debate about students' science performance when exposed to English as a medium of instruction instead of mother-tongue instruction. Instruction in a second language may also relate to poor conceptual understanding and the prevalence of certain misconceptions. Educational

researchers need to recognise that there are language problems associated with science education. The majority of SA learners study a wide variety of school subjects in a language that is not their mother tongue (Probyn, 2004).

(iii) *Previous performance in Mathematics and Science.*

Several studies have been conducted around the world, which revealed that a science and mathematical background has a significant impact on academic performance and success in undergraduate programs (Kelley 2010). Frost (2004), for example, reported that mathematical skills are essential for academic success, in especially the healthcare and engineering professions. In SA, however, studies that the researcher is aware of have not been decisive regarding the relationship of performance in Grade 12 Mathematics and Science and the performance of undergraduate students.

(iv) *Previous performance in English.*

Participant's linguistic ability in English was of importance as it might provide insights into the prevalence of certain misconceptions (Setati et al., 2002). Both the biographical questionnaire (Annexure A) and the DIRECT-instrument were set in English. The researcher also expected that those participants who had obtained a higher average for English upon completion of their matric examination would naturally have had an advantage above those who were not very confident with English as a language and would perform better in the DIRECT-instrument.

(v) *Exposure to practical work at school.*

It was expected that participants who were experienced in making use of laboratory apparatus to perform experiments and or investigations regarding simple DC-electric circuits in small groups would naturally have an advantage (Bereiter, 2002; Cress & Kimmerle, 2018; Michaelides, 2003; Lee et al., 2006, 2007). They have the practical experience of circuits and the skill to establish a logical argument for any of the diagnostic tool's test-items. The CAPS curriculum requires all SA schools to incorporate practical sessions as part of their teaching practices in Physical Science.

(vi) *The gender of the participants.*

There is much debate about gender performance in Science, Mathematics, and Technology (SMTe) related fields (Franke & Bogner, 2011; Mason et al., 2006). The literature further shows concern about female participation and performance in academic physics (Bates, et al., 2012), indicating that males are generally more interested in following careers based on Science and Mathematics.

(vii) *The participants' attitudes towards the subject Physical Science.*

This was an important contextual factor to consider as the literature indicates that attitudes are mostly found as having meaningful relations with science achievement (Tekiroğlu, 2005).

The study used quantitative methods to analyse participants' responses to the contextual factor- questionnaire (Annexure A) as well as their responses in the diagnostic tool (Annexure B). The diagnostic tool used to explore participants' conceptual understanding regarding simple DC-electric circuits was the DIRECT-instrument, a gold standard diagnostic test for conceptual understanding in physics regarding electric circuits that has been standardised and validated by Engelhardt and Beichner (2004). The DIRECT-instrument consists of 29 multiple-choice questions. It does not require algebraic calculations involving DC-electric circuits or consider participants' reasoning. The objective is only to investigate participants' conceptual knowledge of DC-electric circuits and the workings of the different components within an electric circuit. The DIRECT-instrument does not aim to know why students tend to think the way they do, but rather to gather information about what they do know, and what they don't.

This study commenced at a well-established SA University, where 815 participants took part anonymously. Large sample sizes were desired to reduce the magnitude of sampling error (Best, 1981). During data collection, it was not established from what province each participant came, however, one might speculate that the participants represent at least four of the nine provinces in SA when considering the demographic of the entire university.

This research study is based on secondary analysis of empirical data produced by objective measurement in the form of a cross-sectional survey design that was not

influenced by any personal bias but rather valued precision in analysing the already collected data. The sample of participating students was selected on the grounds of convenience, as they enrolled for any of the four first-year physics modules offered at the particular SA university.

To ensure validity, each participant completed the DIRECT-instrument before receiving formal lectures on *electric circuits* within their different university modules. This was done to ensure that this study only gathered data about participants' conceptual understanding of *electric circuits* prior to tertiary instruction, thereby indicating the nature of students' conceptual understanding developed during their school career.

Table 6.1 provides a summary of the methods used in investigating the two sub-research questions of this study. In the text, the research question is addressed. First, the conceptual understanding is discussed in terms of the four critical outcomes. Secondly, the contextual factors that the researcher found to be related to students' conceptual understanding of simple DC-electric circuits are highlighted to address the research questions outlined in the study. In the final section of the study, the limitations are discussed under the reflections. Recommendations for the learning and teaching of the topic as well as the directions for future research are discussed towards the end of this chapter.

**Table 6.1: Methods summary**

| <b>Methods</b>               | <b>Students' understanding of core concepts</b>                                                                                                     | <b>Students' contextual factors</b>                                                                   |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| <b>Research sub-question</b> | How can students' understanding of DC-electric circuits be characterised in terms of critical concepts within the topic?                            | How does the students' conceptual understanding of DC-electric circuits relate to contextual factors? |
| <b>Research approach</b>     | Quantitative                                                                                                                                        |                                                                                                       |
| <b>Participants</b>          | Selected on convenience, entering a first-year university physics course                                                                            |                                                                                                       |
| <b>Instruments</b>           | DIRECT-Instrument                                                                                                                                   | biographical questionnaire                                                                            |
| <b>Data analysis</b>         | Rasch analysis:<br>Individual item location values<br>Individual fit residual values<br>Overall fit statistics<br>Response dependence<br>ICC-curves | Rasch analysis:<br>Unidimensionality and DIF<br>ANOVA<br>Person frequency distribution graphs         |

### 6.3 Answering the Research Questions

Although the DIRECT-instrument provides a quantitative view of students' conceptual understanding of simple DC-electric circuits, it does not consider each student's contextual factors, which could have possibly contributed to variations in performance.

The study set out to explore the nature of first-year university students' conceptual understanding of simple DC-electric circuits, considering those contextual factors that make up part of their everyday context.

Furthermore, the study sought to answer the following research question:

Primary research question:

*What is the nature of conceptual understanding about DC-electric circuits amongst students entering a first-year physics module at a South African University and how does this understanding relate to contextual factors?*

Secondary research question:

- (i) *How can students' understanding of DC-electric circuits be characterised in terms of critical concepts within the topic?*
- (ii) *How does students' conceptual understanding of DC-electric circuits relate to contextual factors?*

#### 6.3.1 Research Sub-Question 1

*How can students' understanding of DC-electric circuits be characterized in terms of critical concepts within the topic?*

The participants' conceptual understanding is discussed in terms of the objectives and outcomes tested by the DIRECT-instrument, summarised according to Table 6.2.

**Table 6.2: Summary of objectives and outcomes**

| <b>OBJECTIVE(S)</b> |                                                                                                  |                      | <b>OUTCOMES</b>                                                                                             | <b>%<br/>CORRECT</b> |
|---------------------|--------------------------------------------------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------------------------------|----------------------|
| <b>NUMBER</b>       | <b>DESCRIPTION</b>                                                                               | <b>%<br/>CORRECT</b> |                                                                                                             |                      |
| 1                   | Short circuit<br>(Questions: 10, 19, 27)                                                         | 48.1%                | Physical aspects of a simple DC-electric circuit<br><br>(Questions 4, 5, 9, 10, 13, 14, 18, 19, 22, 23, 27) | 50.4%                |
| 1 – 3 & 5           | Circuit layout<br>(Questions: 4, 9, 10, 13, 18, 19, 22, 27)                                      | 47.7%                |                                                                                                             |                      |
| 2 & 3               | Locating contact points on screw-type bulb and Complete circuit<br>(Questions: 9 & 18)           | 47.8%                |                                                                                                             |                      |
| 1, 2 & 3            | Short circuit, Locating contact points on screw-type bulb and Complete circuit<br>(Question: 27) | 49.7%                |                                                                                                             |                      |
| 4                   | Resistance<br>(Questions: 5, 14, 23)                                                             | 57.7%                |                                                                                                             |                      |
| 5                   | Diagrams<br>(Questions: 4, 13, 22)                                                               | 47.3%                |                                                                                                             |                      |
| 6                   | Power<br>(Questions: 2 & 12)                                                                     | 44.6%                | Energy<br><br>(Questions 2, 3, 12, 21)                                                                      | 50.1%                |
| 7                   | Conservation of energy<br>(Questions: 3 & 21)                                                    | 55.7%                |                                                                                                             |                      |
| 8                   | Conservation of current<br>(Questions: 8 & 17)                                                   | 56.6%                | Current<br><br>(Questions 1, 8, 11, 17, 20)                                                                 | 37.1%                |
| 9                   | Micro-macro aspects of DC electric circuits (Questions: 1, 11 & 20)                              | 24.1%                |                                                                                                             |                      |
| 10                  | Ohm's Law<br>(Questions: 7, 16, 25)                                                              | 60.1%                | Potential Difference<br><br>(Questions 6, 7, 15, 16, 24, 25, 28, 29)                                        | 43.3%                |
| 11                  | Potential difference in series vs parallel connections<br>(Questions: 6, 15, 24, 28, 29)         | 33.2%                |                                                                                                             |                      |
| 8 & 11              | Current and voltage                                                                              | 41.1%                | 26                                                                                                          |                      |

Participants achieved an average of slightly above 50% for the outcomes of physical aspects of a DC-electric circuit (50.4%) and energy (50.1%). They tested the weakest outcomes of *current* (average score of 37.1%) and *potential difference* (average score of 43.3%), with *current* being the outcome needing the most attention

*i. Outcome 1: Physical aspects of DC-electric circuits.*

Participant's ability to understand the effects of a short circuit was tested in several questions within this outcome. It is a serious problem if almost half of the first-year university students do not understand the basic concept of a short circuit, impacting their ability to understand more complex circuits. Regarding realistic circuit diagrams, participants could easily translate from a realistic representation of a circuit to the corresponding schematic diagram. However, the majority found it challenging making the reverse translation.

The misconceptions associated with the physical aspects of the circuit related to features of the circuit (Table 6.2). Such misconceptions included: *topology*, *contacts*, and *term confusion* (current with resistance). The topological errors participants made indicate that they only consider the surface features of the circuit. Locating the contact points of a light bulb was problematic. The contact error indicates that students are unsure how to locate the contact points on a screw-type light bulb. Errors associated with the circuits' physical aspects can be categorised as students not conceptually understanding the physical nature of the circuit diagram and its associated elements.

*ii. Outcome 2: Energy*

Although SA students seemed to understand energy-related principles better than the other three outcomes of this study, many participants still struggled to understand the difference between cells connected in series and parallel.

*iii. Outcome 3: Current*

Overall, students performed the worst in the objective of current. Questions related to current revealed that students might believe that current causes voltage. If one increases, the other also increases for all components, regardless of whether it is a series/parallel connection. Students seemed to struggle the most with questions

1, 11, and 20 (Objective 9) dealing with DC-electric circuits' micro/macro aspects regarding current. This can be ascribed to the SA physics curriculum, which does not mention how charged particles and the electric field behave inside conducting wires and resistors. However, some teachers might have taught these concepts to their learners, but in the curriculum it is not required. Questions 1, 11, and 20, therefore, indicated some curriculum issues; however, it was Question 20, but not 11, that was excluded from the Rasch analysis due to not fitting test statistics (Chapter 4).

Many answers also indicated errors such as:

- Battery superpositioning.
- Increasing the current increases the resistance.
- Current that passes through light bulbs that are connected in series is consumed by the bulb which is near the positive pole of the battery.

iv. *Outcome 4: Potential difference*

Students appeared to have difficulty answering questions regarding the potential difference in parallel connections (Objective 11, regarding questions 6, 15, 24, 28, 29). Objective 10 (questions 7, 16, 25) regarding Ohm's law, was answered best. Also, two misconceptions combine into a correct answer in question 16, therefore making the question seem 'easy'.

The dominant misconceptions relevant to questions 15, 6, 28, and 29 are: *battery as a constant current source*, *term confusion* (current with voltage), *local reasoning*, and *battery superposition*, summarized in Table 6.3 (p.153). These misconceptions relate to students' lack of conceptual understanding regarding the properties of the cell and what it supplies to the circuit, with the exception of local reasoning. Believing that an increase in the resistance would increase the current seems to be a common tendency.

In conclusion, most challenges associated with circuit concepts can be ascribed to the nature of the content itself, especially between current, voltage, and resistance. The interaction between these variables were the most difficult for SA students to understand.

Concepts of potential difference, current, resistance, and energy seemed to be commonly used interchangeably and were at times used as the same things. Table 6.3 summarises the misconceptions based on the results from the DIRECT-instrument, indicating that SA students tend to have several misconceptions with regards to *electricity and electric circuits*.

**Table 6.3: Illustration of occurring misconceptions in a South African context**

| <b>Misconception</b>                 | <b>Question and relevant option on DIRECT</b>                          | <b>AVERAGE USE SOUTH AFRICA (%)</b> |
|--------------------------------------|------------------------------------------------------------------------|-------------------------------------|
| Battery superposition                | 3e ; 12a                                                               | 23.5                                |
| Battery as a constant current source | 2c ; 3b ; 7c ; 10c ; 15a<br>21e ; 25c ; 26a ; 26b ;<br>26e ; 29a       | 25                                  |
| Complete circuit                     | 9c ; 9e ; 18a ; 18e ;<br>27a ; 27c ; 27d ; 29c                         | 16                                  |
| Contacts                             | 9c ; 9e ; 22a ; 22c<br>22d ; 22e ; 27a ; 27c<br>27d                    | 14                                  |
| Current consumed                     | 6a ; 6b ; 8a ; 8b ; 10c<br>17c ; 21b ; 21c ; 26a<br>26b                | 21                                  |
| I cause E                            | 20c                                                                    | 62                                  |
| Local reasoning                      | 3b ; 10e ; 29a                                                         | 29                                  |
| Equivalent resistance                | 10d ; 15a                                                              | 23                                  |
| Resistive Superpositioning           | 5c ; 14a ; 28d ; 29d                                                   | 20                                  |
| Rule application error               | 2a ; 5a ; 23a                                                          | 10                                  |
| Sequential reasoning                 | 2c ; 26a ; 26b ; 29a                                                   | 28                                  |
| Term confusion – I vs E              | 1c                                                                     | 30                                  |
| Term confusion – I vs R              | 23d                                                                    | 34                                  |
| Term confusion – I vs V              | 6a ; 6b ; 15a ; 17e ;<br>24a ; 28a                                     | 31                                  |
| Topology                             | 4e ; 10c                                                               | 32                                  |
| Short circuit                        | 4e ; 10a ; 10b ; 10c<br>18b ; 18d ; 22a ; 22c<br>22d ; 27a ; 27c ; 27d | 18                                  |

As a result, this study indicates that many students entering a first-year physics module have several misconceptions about electric circuits. It is believed that most of these misconceptions originated from participants' experiences of daily life. However, this study proves that these misconceptions have not been eliminated during students' secondary school careers. Universities should attempt to address these misconceptions amongst their new first-year students.

### 6.3.2 Research sub-question 2

*How do students' conceptual understanding of DC- electric circuits relate to contextual factors?*

The person frequency distribution graphs were used to examine and analyse the relationships between students' conceptual understanding regarding DC-electric circuits and their contextual factors. The results revealed that most of the contextual factors indicated significant differences between groups concerning the conceptual understanding of simple DC-electric circuits, except for *exposure to practical work*.

The person frequency distribution curves revealed the following in terms of the contextual factors that were taken into consideration:

#### Schools visited:

Participants that received their schooling in the FET-phase at private schools and city schools performed better on the diagnostic tool. During their schooling years, these learners developed a better conceptual understanding of DC-electric circuits than those who completed their matric year at a rural or township school.

Although Home language was a contextual factor that was included in the biographical questionnaire (ANNEXURE A), the performance of language groups relating to conceptual understanding is not compared due to the fact that home language is implicitly linked to the type of school attended (chapter 5).

#### Previous performance in Physical Science, Mathematics and English:

Those participants that had achieved a Level 7 (80%–100%) and Level 6 (70% - 79%) in their final Grade 12 Physical Sciences exam performed better on the diagnostic tool. These learners developed a better conceptual understanding of DC-electric circuits than those who indicated having achieved a Level 3 (40%–49%) in their matric year. Learners achieving a Level 3 performed the weakest on the diagnostic tool and probably had more deeply rooted misconceptions.

Participants that achieved a Level 7 (80%–100%) and Level 6 (70%79%) in their final Grade 12 Mathematics exam performed better in the diagnostic tool compared to those who had achieved a Level 4 (30%39%) in their final Mathematics exam, indicating a better conceptual understanding of DC-electric circuits. This was an interesting

observation as none of the test-items required participants to do any mathematical calculations. This probably indicates that those participants who had achieved good marks (Level 7 or 6) in Mathematics during their schooling years could apply the reasoning skills taught to correctly answer the test items. They developed a better conceptual understanding of DC-electric circuits than those who had achieved a Level 4 in their final Mathematics exam.

Participants that achieved a level 7 (80% - 100%) and level 6 (70% - 79%) in their final grade 12 English exam performed better in the diagnostic tool compared to those who had achieved a level 4 (30% - 39%). Since the diagnostic tool was set in English, this observation indicates:

- Participants with a better linguistic ability in English had a better conceptual understanding regarding DC-electric circuits.
- Proficiency in English, may therefore support SA learners' conceptual understanding of simple DC-electric circuits. Educational authorities need to recognise that there are language problems associated with science education (Gudula, 2017). The majority of SA learners study a wide variety of school subjects using a language that is not their vernacular (Probyn, 2004). Yet, they are required to conceptually understand the content in all of these subjects while being challenged to interpret content from their home language to the English language of instruction.
- The positive relationship between the DIRECT-instrument's results and previous Physical Science, Mathematics, and English performance is not surprising. According to Bloom (as cited in Tekiroğlu, 2005), students tend to have certain perceptions about their past and expected future performances according to the judgments about their marks. Past achievement affects students' future achievement. This is true regarding students' performance in Physical Science, Mathematics, and English.

As expected, participants that had enrolled for a course that required very high admission criteria also seemed to have performed better on the diagnostic tool. In this study, the engineering students performed the best, while those entering the extended program performed the worst. This implies that the engineering students had a better conceptual understanding of DC-electric circuits, while those students entering an extended physics

module displayed the weakest conceptual understanding of DC-electric circuits. However, the study did not focus on students' performance concerning the particular physics courses studied at university.

#### Exposure to practical work:

There was no significant difference in the performance of participants exposed to practical work using circuit apparatus while working in small groups, compared to those that were not. This is interesting, as this result contradicts the literature (Bereiter, 2002; Cress & Kimmerle, 2018; Michaelides, 2003; Lee et al., 2006). Moreover, the Department of Basic Education (DoBE, 2013) highlighted in their diagnostic report about the 2012 NSC examinations that students' answers indicated that they did not participate in practical work or demonstrations (DoBE, 2013), especially those students who struggled to answer the question regarding simple DC-electric circuits correctly.

According to McDermott and Shaffer (1992), exposure to laboratory-based hands-on activities can offer special benefits to conceptually understand concepts regarding *electricity and electric circuits* and may be used for correcting misconceptions. However, some misconceptions are so strong and resistant that even direct experience with the real phenomena may not always be effective for changing students' opinions (Ronen & Eliahu, 2000).

#### Gender:

The results of this study indicated that males had a better conceptual understanding of DC-electric circuits than females. However, it should be highlighted that more males had participated in this study than females. Also, most of the males who took part in this study had enrolled for an engineering course. This automatically put the males in a favourable position as the engineering course had the highest entrance requirement. When investigating conceptual understanding within science, the literature indicates that gender, grade, and reasoning ability could influence a students' conceptual understanding (Lin et al., 2016). To support this, past research on gender, especially in science, has compared males to females based on personal epistemology, ability, motivation as well as the difference in their interests to examine and formulate cultural and developmental explanations of documented differences (Mason, Boldrin, & Zurlo, 2006).

Kahle and Meece (1994) initially pointed out that gender-related differences regarding science performance tend to be insignificant in primary school but increase as students progress through to secondary schooling. As a result of how family and culture help shape gender relationships, both males and females commonly perceive Physical Sciences and engineering courses as more masculine. This may be why more males who had participated in this study enrolled for an engineering or Physical Science course (Table 5.3 p.123). Not only did more males enrol, but on average, the males performed better than the females who enrolled.

#### Attitude to Physics:

Participants that indicated that they had a keen interest in Physical Sciences and that they did well in the subject had a better conceptual understanding of DC-electric circuits than those who indicated that they did not like the subject and performed poorly in it. In the literature, attitudes are mostly found as having meaningful correlations with science achievement (Tekiroğlu, 2005). Once a student experiences a positive achievement, they develop a positive attitude towards the subject. By the force of these optimistic thoughts, they would be more willing and patient to attempt further studying, producing more positive results. However, developing a positive attitude can be different for all students. The shared the vision of these researchers (Park & Lee, 2004; Tekiroğlu, 2005) is that achievement and attitudes of science are affected by each other and so have a mutually supportive relationship.

Students develop negative attitudes towards physics because they tend to think that physics is irrelevant to the real-world or limited to an ideal laboratory (Park & Lee, 2004). Seeing the links of physics with everyday life can cause greater interest in physics. Moreover, Koçyiğit (2003) found a negative correlation coefficient between scores of misconceptions about static electricity and scores of attitudes, implying that students interested in science tend to have a better conceptual understanding of the content. The current study supports Koçyiğit's results.

#### **6.3.3 Primary research question**

*What is the nature of conceptual understanding about DC-electric circuits amongst students entering a first-year physics module at a South African University, and how does this understanding relate to contextual factors?*

In this study, the overall fit statistics, which were an indication of how well the data fit the Rasch model, were considered first. Thereafter, individual items were analysed using the fit residual statistics and the ICCs together with qualitative content analysis. The content analysis comprised of the implicit analysis relating to categories of relevant misconceptions, curriculum content as well as possible confusion as a result of the formulation of questions. It was evident that, by eliminating test-items that seemed not to fit the sample, the instrument produced better fit statistics. No significant response dependence or multidimensionality was detected between items. This analysis revealed that the test followed good test design principles because the data fitted the model well. The person–item location distribution showed a reasonable spread of items and persons, and the test was targeted well at the sample. The results further suggest that questions that combined objectives and those involving problem solving were beyond many of these students' competencies. This study was carried out with 815 first-year university students representing approximately 0.5% of the 178 887 students matriculating with Physical Science in 2012. The results should not be interpreted as reflecting the entire school group in SA, as many of these students do not enrol for a physics module or do not even go to university. However, it can be concluded that the entire Gr 12 Physical Science group would display an even worse conceptual understanding, indicating that the SA schools have an overall worse conceptual understanding of basic DC-electric circuits than most other countries.

Furthermore, the type of misconceptions SA students have of simple DC-electric circuits appear not to be so different compared to other countries (Engelhardt & Beichner, 2004) which is not surprising as misconceptions are universal (Bernhardt & Carstensen, 2015; Clement & Steinberg, 2002; Driver, 1989; Engelhardt & Beichner, 2004; Gaigher et al., 2007; Gaigher, 2014; Gunstone et al., 2009; Hofer et al., 2017; Zimmerman, 2015). However, it is not always a very easy task to distinguish between a misconception, a lack of knowledge, or students having the inability to reason correctly. It has also been made clear from the results that students who seemingly appear to understand a concept in one situation failed to apply it in another question that requires more complex reasoning where objectives are combined. In this sense, one could think of conceptual understanding as the constantly evolving knowledge, but testing the understanding of concepts is by no means straightforward. In his paper Di Sessa (1998) writes that knowledge has to be coordinated, and depending on the situation, a deeper structure of

the concepts or relationships might also need to be invoked. He highlights that to attain a higher degree of conceptual understanding, one should regard the teaching process to be equally important as the content.

It was also observed that participants could not clearly distinguish between basic concepts of electric circuits such as current, potential difference, resistance, and energy. Participants tend to use them interchangeably.

A lack of knowledge of short circuits, cells in parallel, bulb connections simple series, and parallel connections also seemed to be problematic.

The results revealed some significant relationships between students' degree of conceptual understanding and the following contextual factors:

- (i) *The type of school.* Participants that attended private schools and city schools had a better conceptual understanding of DC-electric circuits.
- (ii) *The average mark obtained for Physical Science at the end of secondary schooling.* The better participants performed in Physical Science at the end of their matric year, the better their conceptual understanding of DC-electric circuits.
- (iii) *The average mark obtained for Mathematics at the end of secondary schooling.* The better participants performed in Mathematics at the end of their matric year, the better their conceptual understanding of DC-electric circuits.
- (iv) *The average mark obtained for English at the end of secondary schooling.* The better participants performed in English at the end of their matric year, the better their conceptual understanding of DC-electric circuits.
- (v) *Gender.* Although the males outperformed the females, it should be noted that more males participated in this study compared to females.
- (vi) *Personal beliefs and attitudes.* Participants who displayed more positive attitudes towards Physical Science had a better conceptual understanding of DC-electric circuits' principles.

However, contrary to expectations, exposure to practical work did not show a significant relation to the conceptual understanding of DC-electric circuits. Figure 6.1 gives a clear summary of the study with its key findings in a mind map form.

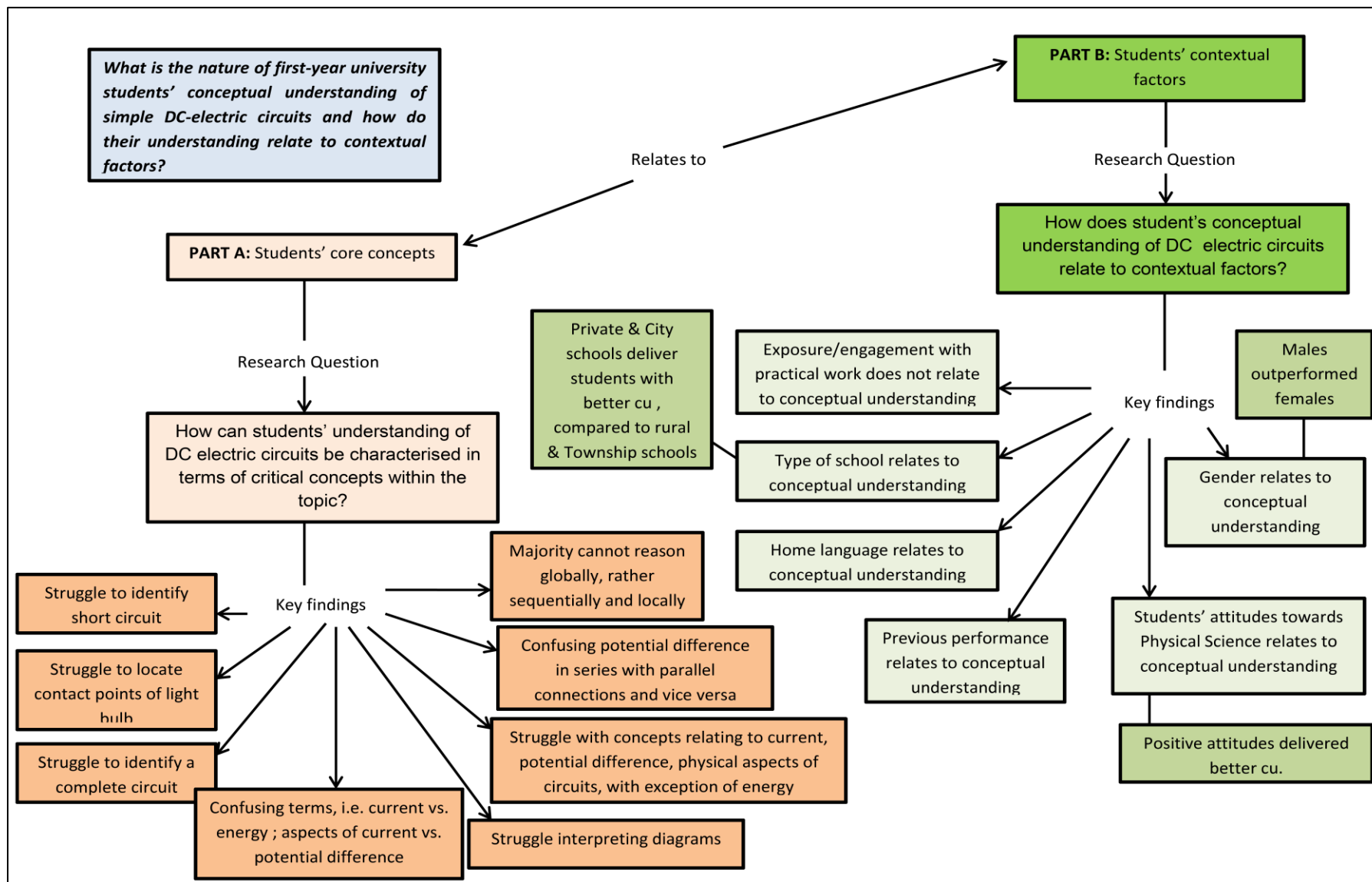


Figure 6.1: Summary of key-findings

## 6.4 Reflection on the Conceptual Framework of the Study

The current research began by designing a conceptual framework based on previous studies and proposing a model for exploring the conceptual understanding of simple DC-electric circuits in Physical Science education (Figure 6.2). The conceptual framework was based on a combination of Engelhardt and Beichner's (2004) model of conceptual understanding of DC-electric circuits and a model on the effectiveness of science education in SA, developed by Cho et al. (2014). Following Engelhardt and Beichner, the framework assumes that the conceptual understanding of DC-electric circuits, as developed during schooling, can be described in terms of four critical outcomes.

Furthermore, students' conceptual understanding of simple DC-electric circuits cannot be explored in isolation but should consider the environment surrounding students, namely contextual factors. For that reason, the model for exploring the degree of conceptual understanding should include contextual environments. The conceptual framework focuses on six contextual factors influencing student achievement. These contextual factors relate to the learning climate within the school (type of school), the classroom (teaching methods, language of instruction) and the students' characteristics (gender), previous performance (in Physical Science, Mathematics and English), and motivation (beliefs and attitudes). These contextual factors relate to the four outcomes of achievement in the DIRECT-instrument (conceptual understanding of DC-electric circuits' *physical aspects, energy, current and potential difference*).

It should be noted that the model adapted from the analysis of the data was limited to the contextual factors investigated in this study and the scientific topic, i.e. DC-electric circuits. The proposed model, see Figure 6.2, may be expanded when considering other contextual factors relating to conceptual understanding of any scientific topic.

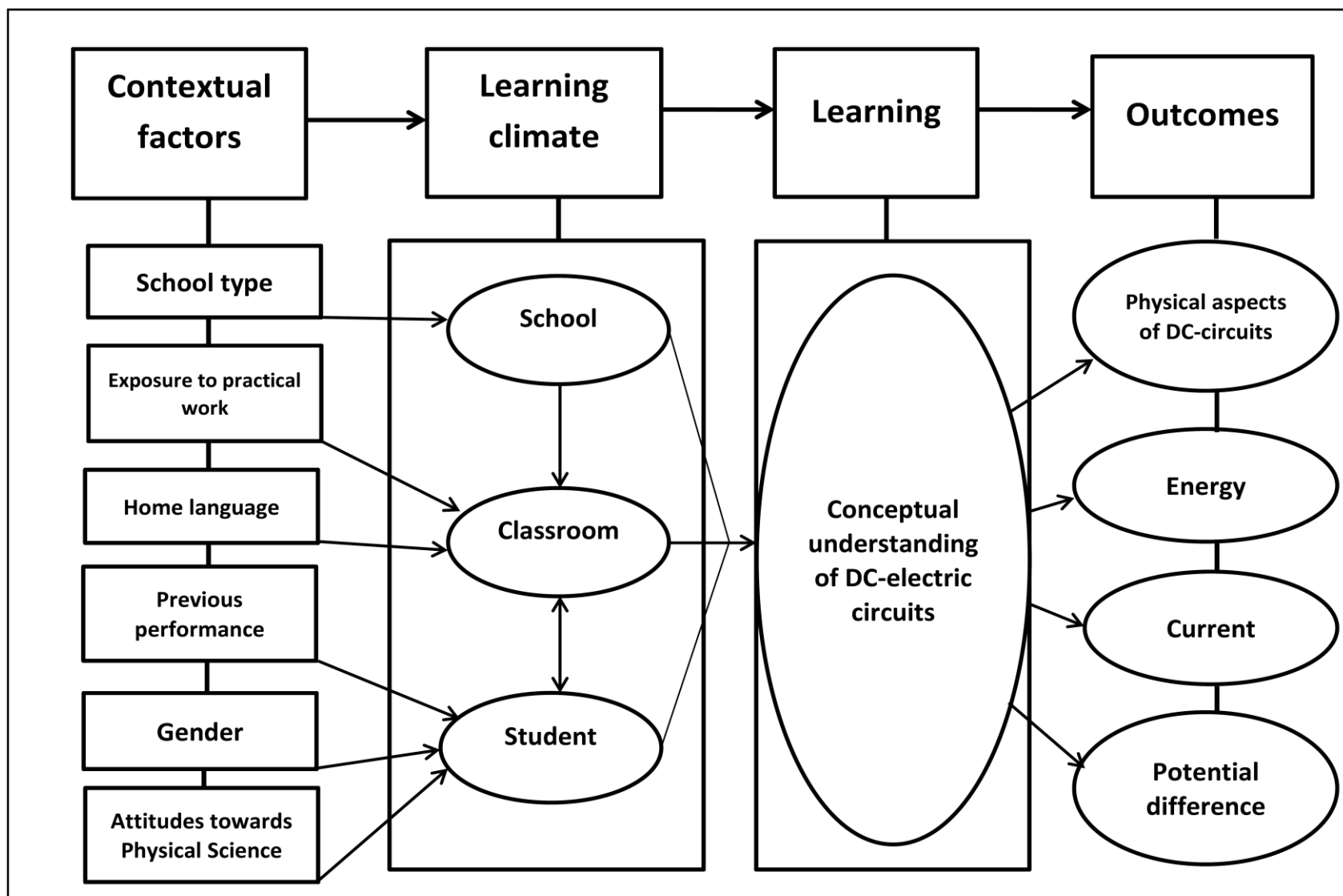


Figure 6.2: Conceptual framework in this study

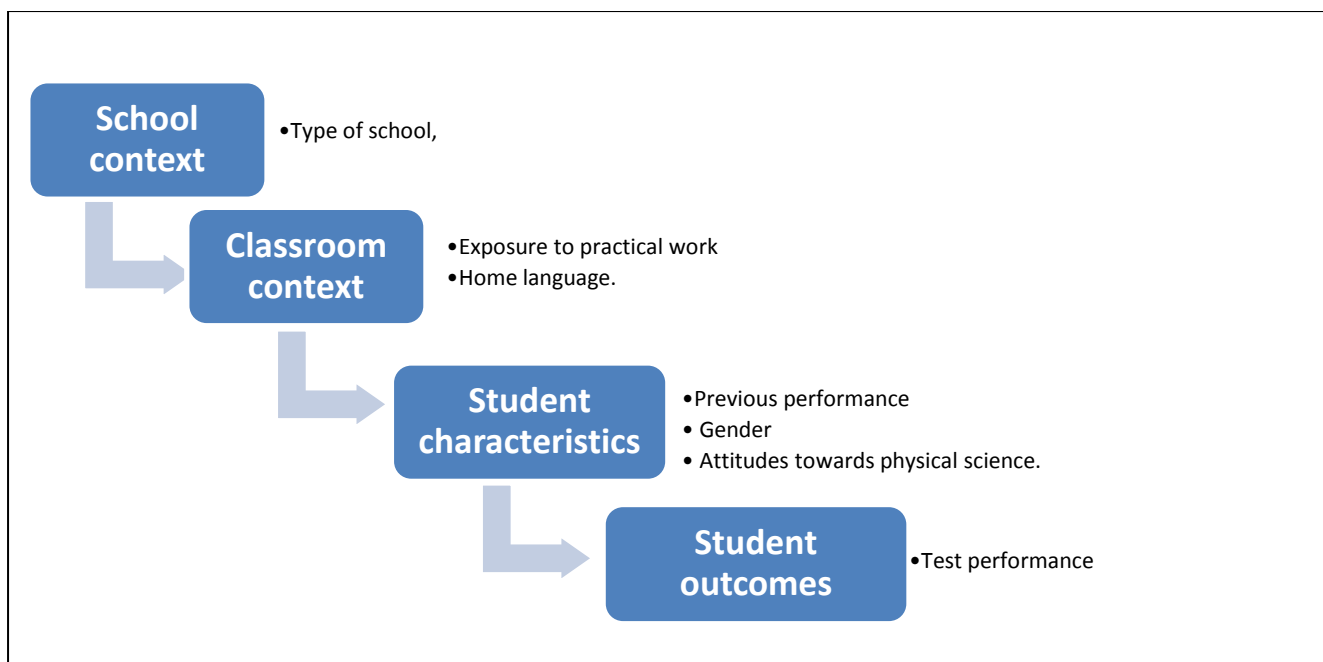


Figure 6.3: Contextual factors contributing to student outcomes

## 6.5 Limitations of the Study

The single most significant limitation of this study was the type of university as this university has a very large engineering faculty, while many other SA universities do not offer engineering. This characteristic automatically excludes students enrolled for physics modules at other universities and physics courses at local community colleges and does not reflect the degree of conceptual understanding of electric circuits of all of SA's nine provinces. This study only includes students who had obtained university exemption at the end of their matric year (access to degree studies). Therefore, they would naturally exclude students passing their matric with access to Diploma or Certificate-studies. This means that the results do not reflect the degree of conceptual understanding of the typical SA student within a SA context. The sample also varied in terms of gender. More males took part in this study than females as there is a tendency that more males choose physics than females. The sample size and type are a limitation; however, it does not reduce the validity of the results obtained from the diagnostic tool used.

The diagnostic tool itself consisted only of multiple-choice test items. There was a possibility that participants who found the test-items difficult and challenging could have guessed the correct answer. An option to explain their answer would have

encouraged participants to make an argument for their viewpoint. Besides, even if participants had some knowledge of a question, they did not receive any credit for knowing that information if they selected the wrong answer, especially as the test-items were scored dichotomously.

## 6.6 Recommendations for Future Study

- (i) This study's objective was to investigate the nature of conceptual understanding and the contextual factors relating to it, but not to investigate why students tend to think the way they do. Therefore, a future study might be aimed at investigating why students have certain misconceptions, what influences their thinking, and then also suggest possible teaching strategies that would be more applicable to a SA audience. Such a study might want to investigate why students attending rural or township schools are entering a university with a disadvantage regarding the conceptual understanding of DC-electric circuits. Is it perhaps because there are not enough resources available? Are the teachers not adequately trained or qualified, or still inexperienced at teaching? Can this maybe be ascribed to a language problem? Do teachers encourage their learners to ask questions, argue, and criticize, debate, and make suggestions as expected for scientific literacy? These are all possible explanations for students' varying degrees of conceptual understanding. However, the underperformance of students attending rural or township schools can be treated as a separate study, but with the same objectives in mind. Although this study cannot determine with complete accuracy whether participants chose answers based on correct understanding or misconceptions they have or if they were just guessing answers at random. It would therefore be helpful to incorporate a three-tier test based on a pre-post methodology where individual interviews could have solved this problem. A qualitative study would be useful to investigate student reasoning.
- (ii) A future study might want to investigate why the exposure to practical work regarding DC-electric circuits does not relate to students' conceptual

understanding. What teaching practices would be useful to support conceptual understanding regarding *electricity and electric circuits*. How are practical activities with circuit connections carried out in SA?

- (iii) Future studies, similar to the current study, could ensure that equal numbers of males and females in the various physics courses participate. This will provide more insights as to whether the males do outperform the females regarding their conceptual understanding of DC-electric circuits.
- (iv) The students' poor results underscore the urgency of interventions that can succeed in improving SA students' conceptual understanding of simple DC-electric circuits. Therefore, it is recommended that stakeholders such as national and provincial education departments, universities, and subject advisors need to collectively determine the extent of the problem of poor knowledge and then design a systematic intervention that targets those students who require help.
- (v) It is recommended that teachers in the FET-phase place more emphasis on teaching the basic concepts more appropriate for students to gain the ability to distinguish between them without difficulty.
- (vi) A future study might want to focus on why students entering a B.Sc Extended program hold high beliefs regarding their abilities in physics, although their average performance remains low.
- (vii) It would also be insightful to compare misconceptions of the current study (SA) with an international study, when groups are treated the same, as well as the reasons for differences.

## 6.7 Conclusions and Implications

As a result of this study, it was found that students entering a first-year physics module at a SA university have a poor conceptual understanding involving several misconceptions regarding simple DC-electric circuits. The findings of this study can be useful in a Physical Science curriculum development and instructional

improvement. Results indicate that the sample fitted the DIRECT-instrument after excluding four test-items (Items 14, 16, 20, and 28). Questions 14; 16; 20 and 28 resulted in having the largest fit residual values (Chapter 4), deviating significantly from the expected model parameters. For this reason, it was decided that these four test-items should be omitted from the data in an attempt to make the Direct instrument fitting in the SA context.

FET-teachers may also use the DIRECT-instrument as a formative or a baseline assessment tool to provide them with useful insights indicating if any remedial instruction is required or if their teaching techniques require some modification.

The diagnostic tool used was valuable, as it provided insights into participants' conceptual understanding of simple DC-electric circuits. Overall, participants' selected answers revealed their misconceptions and other difficulties. Different test-items signaled different misconceptions.

The content and concepts that were highlighted as problematic in this research study were:

- 1 Series/parallel connections, particularly cells in parallel in a circuit.
- 2 The concept of voltage, particularly how changes within a circuit would affect the voltage, current, resistance, power, and energy transfer within a DC-electric circuit.
- 3 Constructions of simple DC-electric circuits, particularly lacking skills, and conceptual understanding to relate from a realistic description to a schematic representation.
- 4 Identifying a short in a circuit and understanding its effects.
- 5 Terminology also seemed to have been a problem in some questions. The lack of conceptual understanding is exposed by students' poor distinguishing between concepts. Students expressed difficulty in distinguishing accurately between concepts of current with potential difference, as well as current with energy. Although this type of error is not directly referred to in literature, the impact of language usage is potentially an interesting area of study.

Although the diagnostic tool did not always provide definite answers, its results may be used as a point of departure if the study is repeated in the future. It may then be useful to investigate whether SA students are improving their conceptual

understanding of simple DC-electric circuits. Also, not many didactical changes have been made within the CAPS curriculum concerning the teaching of simple DC-electric circuits (Annexure C). For these reasons, one might speculate that students within SA might still experience the same difficulties as the graduating group of 2012 with regards to simple DC-electric circuits.

This research study indicates a poor conceptual understanding of simple DC-electric circuits amongst SA students, yet the same type of results was reported in the USA and Canada (Engelhardt & Beichner, 2004). This research considers the results of the data and concludes that there is a poor understanding of basic concepts and physical aspects of simple DC-electric circuits. Although the curriculum's progression is good across the grades, there remains a problem regarding the learning of physical aspects of circuits, suggesting that students did not learn very basic ideas such as short circuits and parallel connection of cells during earlier years. Circuits are poorly addressed conceptually within the SA Physical Science curriculum. A vital academic question then arises: How can those students be supported at university to improve their conceptual understanding of DC-electric circuits?

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# ***ANNEXURES***

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**Appendix A:****Research Project****Conceptual understanding of DC circuits amongst students  
entering university physics**

Please supply the background information and then proceed with the test on simple electric circuits. Use a pencil to complete the form.

**Background information**

Supply your answers on the computer form, using items 36-45

36 What kind of high school did you attend?

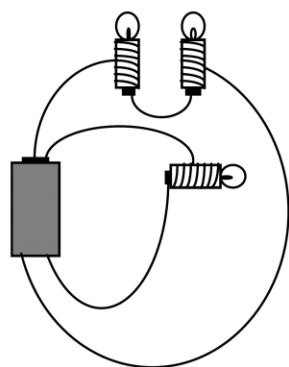
- A rural
- B township
- C inner city
- D ex model C
- E private school

37 Which language do you speak at home?

- A African
- B English
- C Asian
- D Afrikaans
- E other

- 38 What was your score for Physical Science in your grade 12 examination?
- A 7 (above 80)
  - B 6 (70-79)
  - C 5 (60-69)
  - D 4 (50-59)
  - E 3 or less (below 50)
- 39 What was your score for Mathematics in your grade 12 examination?
- A 7 (above 80)
  - B 6 (70-79)
  - C 5 (60-69)
  - D 4 (50-59)
  - E 3 or less (below 50)
- 40 What was your score for English (first or second language) in your grade 12 examination?
- A 7 (above 80)
  - B 6 (70-79)
  - C 5 (60-69)
  - D 4 (50-59)
  - E 3 or less (below 50)
- 41 For which course have you registered at UP?
- A BEng (Engineering)
  - B MBChB (Medicine)
  - C BSc Biological Sciences (any of the life Sciences, eg, Biotechnology, Zoology etc.)
  - D BSc (any of the Physical Sciences, eg. Chemistry, Geology etc)
  - E BSc (4 year programme) Physical Sciences

- 42 For which Physics module are you registered?
- A PHY 131
  - B PHY 114
  - C PHY 133
  - D FSK 116
  - E other
- 43 How did you use apparatus to build circuits in the science class at school?
- A The learners worked in groups to build circuits.
  - B The used one circuit to demonstrate experiments.
  - C We did not use apparatus but the teacher gave us readings from a book so we could complete the reports on the experiments.
  - D A travelling laboratory visited our school and helped us to do experiments.
  - E We visited another school/institute to do our experiments
- 44 Which gender are you?
- A Male
  - B Female
- 45 Which of the following statements best describes your feelings about Physics?
- A I like Physics and I am also good at it.
  - B I like Physics but I am not good at it.
  - C I do not like Physics but I am good at it.
  - D I do not like Physics and am not good at it.



# Determining and Interpreting Resistive Electric Circuits Concepts Test

Version 1.0

## Instructions

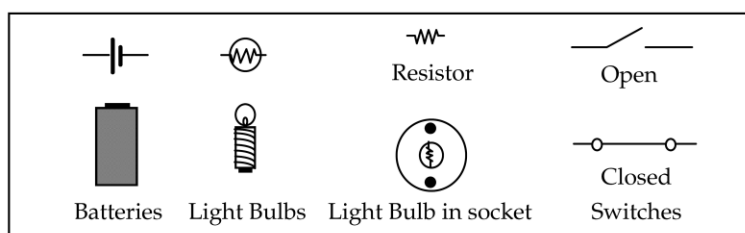
**Wait until you are told to begin**, then turn to the next page and begin working. Answer each question as accurately as you can. There is only one correct answer for each item. Feel free to use a calculator and scratch paper if you wish.

Use a #2 pencil to **record your answers** on the computer sheet, but please **do not write in the test booklet**.

You will have approximately one hour to complete the test. If you finish early, check your work before handing in both the answer sheet and the test booklet.

## Additional comments about the test

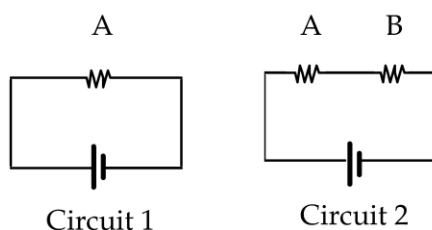
All light bulbs, resistors, and batteries should be considered identical unless you are told otherwise. The battery is to be assumed ideal, that is to say, the internal resistance of the battery is negligible. In addition, assume the wires have negligible resistance. Below is a key to the symbols used on this test. Study them carefully before you begin the test.



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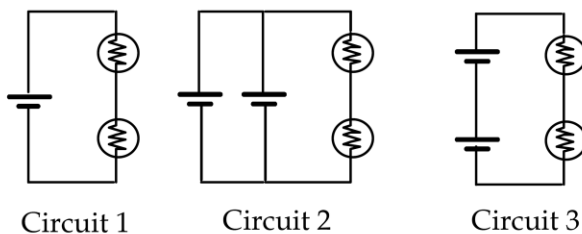
- 1) Are charges used up in a light bulb, being converted to light?
- (A) Yes, charges moving through the filament produce "friction" which heats up the filament and produces light.
- (B) Yes, charges are emitted.
- (C) No, charge is conserved. It is simply converted to another form such as heat and light.
- (D) No, charge is conserved. Charges moving through the filament produce "friction" which heats up the filament and produces light.
- 2) How does the power delivered to resistor A change when resistor B is added as shown in circuits 1 and 2 respectively?

- (A) Increases  
(B) Decreases  
(C) Stays the same

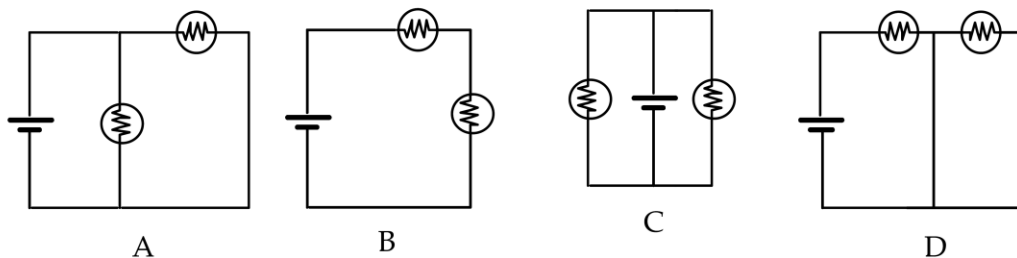


- 3) Consider the circuits shown below. Which circuit or circuits have the greatest energy delivered to it per second?

- (A) Circuit 1  
(B) Circuit 2  
(C) Circuit 3  
(D) Circuit 1 = Circuit 2  
(E) Circuit 2 = Circuit 3



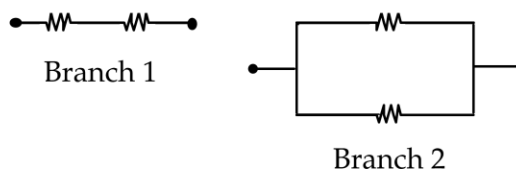
- 4) Consider the following circuits.



Which circuit(s) above represent(s) a circuit consisting of two light bulbs in parallel with a battery?

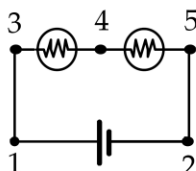
- (A) A  
(B) B  
(C) C  
(D) A and C  
(E) A, C, and D
- 5) Compare the resistance of branch 1 with that of branch 2. A branch is a section of a circuit. Which has the least resistance?

- (A) Branch 1  
(B) Branch 2  
(C) Neither, they are the same



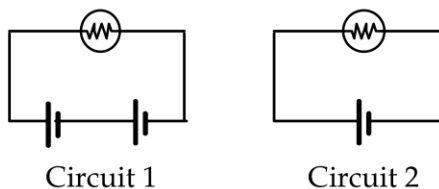
- 6) Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown below from highest to lowest.

- (A) 1 and 2; 3 and 4; 4 and 5  
(B) 1 and 2; 4 and 5; 3 and 4  
(C) 3 and 4; 4 and 5; 1 and 2  
(D) 3 and 4 = 4 and 5; 1 and 2  
(E) 1 and 2; 3 and 4 = 4 and 5



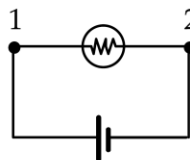
- 7) Compare the brightness of the bulb in circuit 1 with that in circuit 2. Which bulb is brighter?

- (A) Bulb in circuit 1  
(B) Bulb in circuit 2  
(C) Neither, they are the same



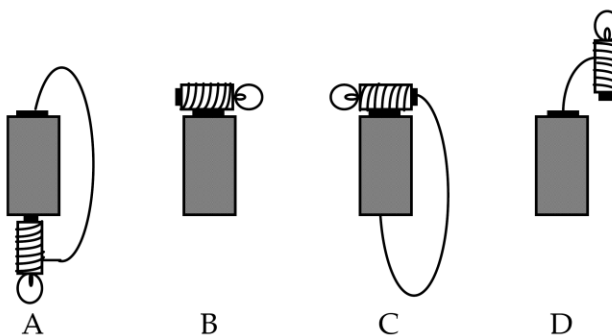
- 8) Compare the current at point 1 with the current at point 2. Which point has the larger current?

- (A) Point 1  
(B) Point 2  
(C) Neither, they are the same



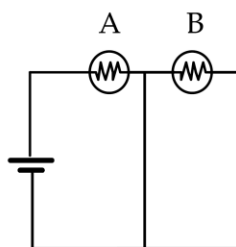
- 9) Which circuit(s) will light the bulb?

- (A) A  
(B) C  
(C) D  
(D) A and C  
(E) B and D

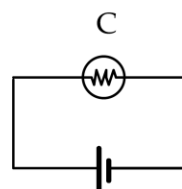


- 10) Compare the brightness of bulbs A and B in circuit 1 with the brightness of bulb C in circuit 2. Which bulb or bulbs are the brightest?

- (A) A  
(B) B  
(C) C  
(D) A = B  
(E) A = C



Circuit 1



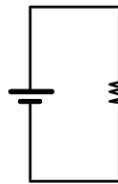
Circuit 2

11) Why do the lights in your home come on almost instantaneously?

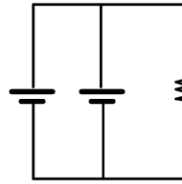
- (A) Charges are already in the wire. When the circuit is completed, there is a rapid rearrangement of surface charges in the circuit.
- (B) Charges store energy. When the circuit is completed, the energy is released.
- (C) Charges in the wire travel very fast.
- (D) The circuits in a home are wired in parallel. Thus, a current is already flowing.

12) Consider the power delivered to each of the resistors shown in the circuits below. Which circuit or circuits have the least power delivered to it?

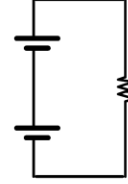
- (A) Circuit 1
- (B) Circuit 2
- (C) Circuit 3
- (D) Circuit 1 = Circuit 2
- (E) Circuit 1 = Circuit 3



Circuit 1



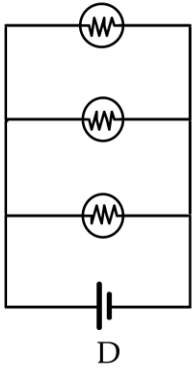
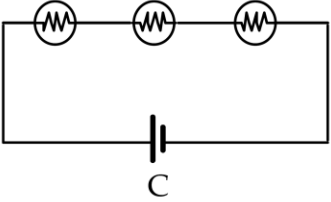
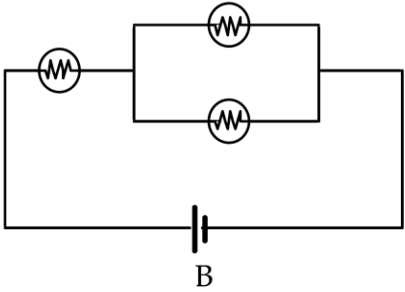
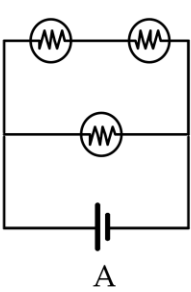
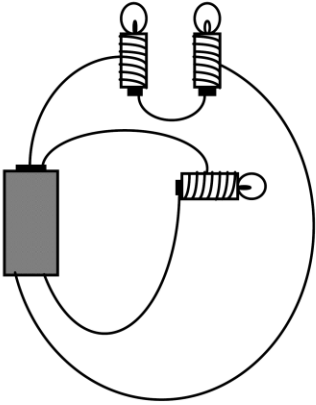
Circuit 2



Circuit 3

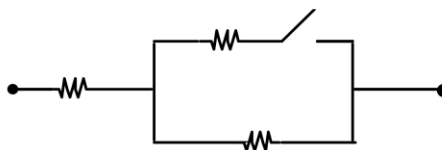
13) Which schematic diagram best represents the realistic circuit shown below?

- (A) A
- (B) B
- (C) C
- (D) D
- (E) None of the above



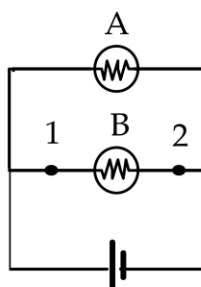
14) How does the resistance between the endpoints change when the switch is closed?

- (A) Increases
- (B) Decreases
- (C) Stays the same



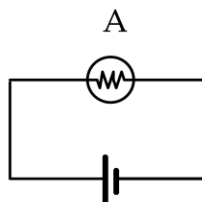
15) What happens to the potential difference between points 1 and 2 if bulb A is removed?

- (A) Increases
- (B) Decreases
- (C) Stays the same

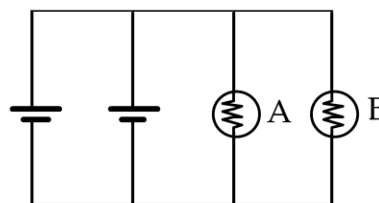


16) Compare the brightness of bulb A in circuit 1 with bulb A in circuit 2. Which bulb is dimmer?

- (A) Bulb A in circuit 1
- (B) Bulb A in circuit 2
- (C) Neither, they are the same



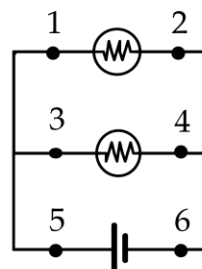
Circuit 1



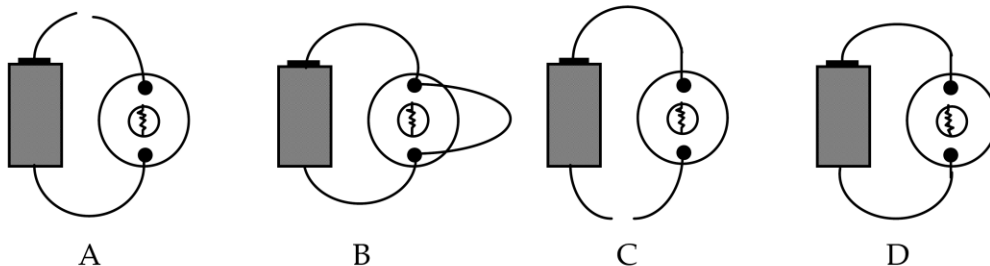
Circuit 2

17) Rank the currents at points 1, 2, 3, 4, 5, and 6 from highest to lowest.

- (A) 5, 1, 3, 2, 4, 6
- (B) 5, 3, 1, 4, 2, 6
- (C) 5 = 6, 3 = 4, 1 = 2
- (D) 5 = 6, 1 = 2 = 3 = 4
- (E) 1 = 2 = 3 = 4 = 5 = 6



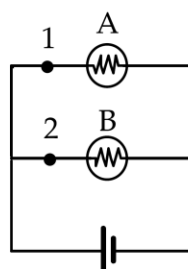
18) Which circuit(s) will light the bulb?



- (A) A
- (B) B
- (C) D
- (D) B and D
- (E) A and C

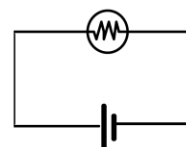
19) What happens to the brightness of bulbs A and B when a wire is connected between points 1 and 2?

- (A) Increases
- (B) Decreases
- (C) Stays the same
- (D) A becomes brighter than B
- (E) Neither bulb will light



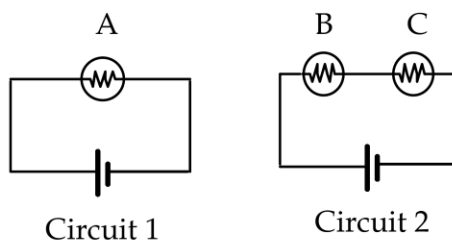
20) Is the electric field zero or non-zero inside the tungsten bulb filament?

- (A) Zero because the filament is a conductor.
- (B) Zero because there is a current flowing.
- (C) Non-zero because the circuit is complete and a current is flowing.
- (D) Non-zero because there are charges on the surface of the filament.



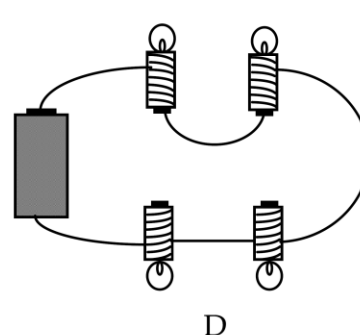
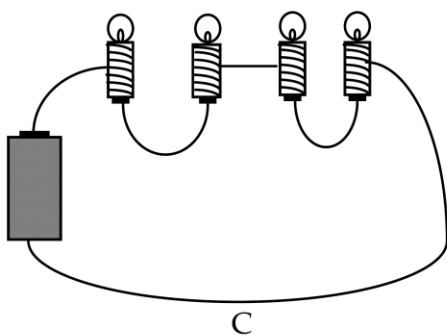
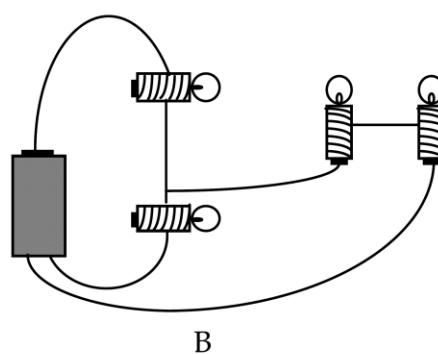
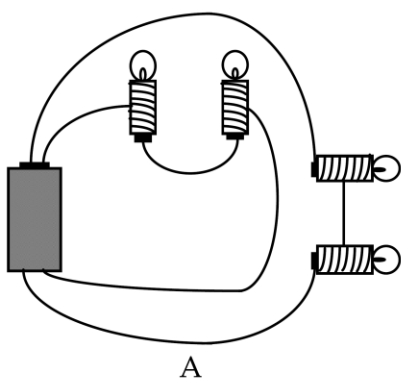
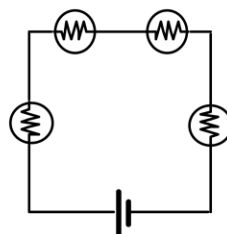
- 21) Compare the energy delivered per second to the light bulb in circuit 1 with the energy delivered per second to the light bulbs in circuit 2. Which bulb or bulbs have the least energy delivered to it per second?

- (A) A  
(B) B  
(C) C  
(D) B = C  
(E) A = B = C



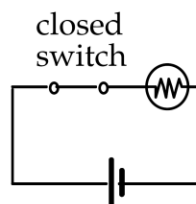
- 22) Which realistic circuit(s) represent(s) the schematic diagram shown below?

- (A) B  
(B) C  
(C) D  
(D) A and B  
(E) C and D



23) Immediately after the switch is opened, what happens to the resistance of the bulb?

- (A) The resistance increases.
- (B) The resistance decreases.
- (C) The resistance stays the same.
- (D) The resistance goes to zero.

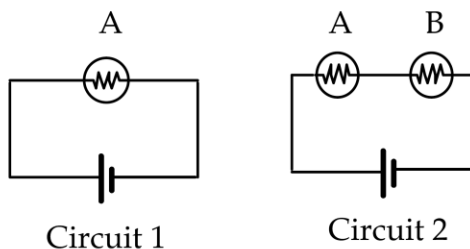


24) If you double the current through a battery, is the potential difference across a battery doubled?

- (A) Yes, because Ohm's law says  $V = IR$ .
- (B) Yes, because as you increase the resistance, you increase the potential difference.
- (C) No, because as you double the current, you reduce the potential difference by half.
- (D) No, because the potential difference is a property of the battery.
- (E) No, because the potential difference is a property of everything in the circuit.

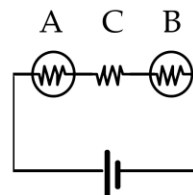
25) Compare the brightness of bulb A in circuit 1 with bulb A in circuit 2. Which bulb is brighter?

- (A) Bulb A in circuit 1
- (B) Bulb A in circuit 2
- (C) Neither, they are the same

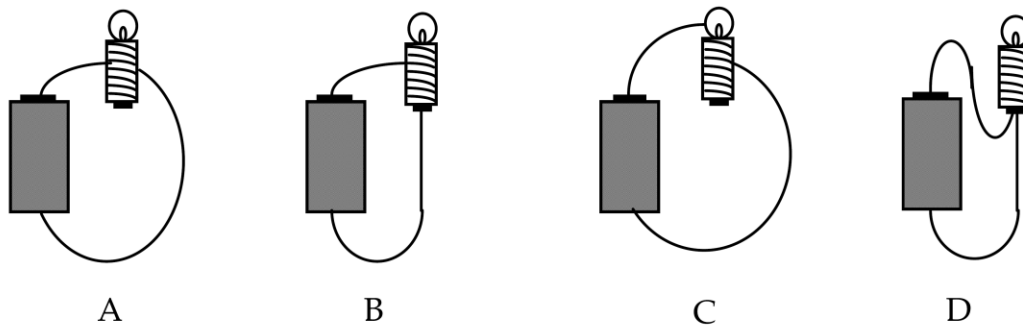


26) If you increase the resistance C, what happens to the brightness of bulbs A and B?

- (A) A stays the same, B dims
- (B) A dims, B stays the same
- (C) A and B increase
- (D) A and B decrease
- (E) A and B remain the same



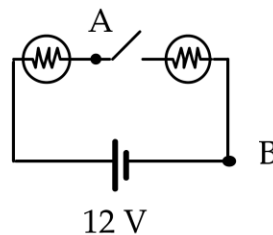
27) Will all the bulbs be the same brightness?



- (A) Yes, because they all have the same type of circuit wiring.  
 (B) No, because only B will light. The connections to A, C, and D are not correct.  
 (C) No, because only D will light. D is the only complete circuit.  
 (D) No, C will not light but A, B, and D will.

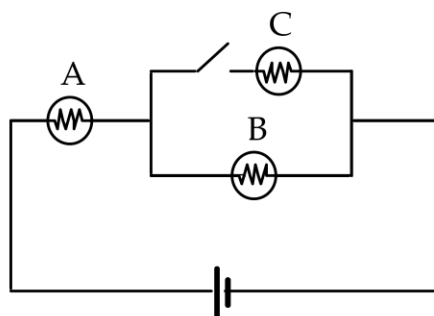
28) What is the potential difference between points A and B?

- (A) 0 V  
 (B) 3 V  
 (C) 6 V  
 (D) 12 V



29) What happens to the brightness of bulbs A and B when the switch is closed?

- (A) A stays the same, B dims  
 (B) A brighter, B dims  
 (C) A and B increase  
 (D) A and B decrease  
 (E) A and B remain the same



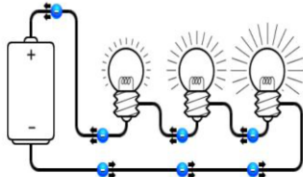
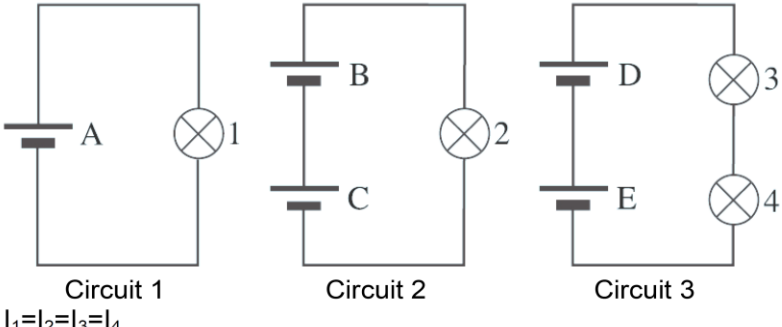
**ANNEXURE C: Summary of the electric circuit content coverage according to the CAPS document (Gr.10-12)**

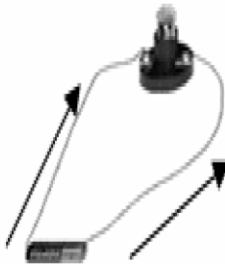
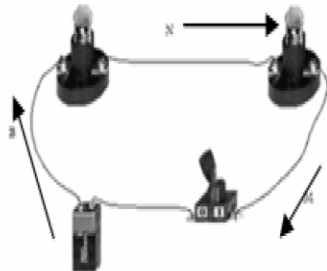
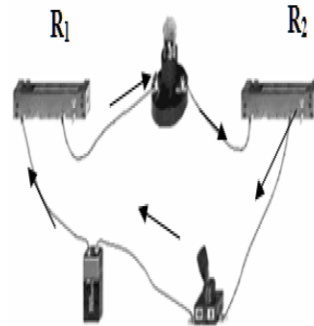
|  | GRADE 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | GRADE 11                                                                                                                                                                                                                                                            | GRADE 12                                                                                                                                                                                                                                                                                    |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | Complete Circuit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                             |
|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <ul style="list-style-type: none"> <li>Determine the relationship between current, voltage and resistance at a constant temperature using a simple circuit.</li> <li>State the difference between Ohmic and non-Ohmic conductors. Give examples of each.</li> </ul> | <ul style="list-style-type: none"> <li>Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel.</li> </ul>                                                                                                     |
|  | Current                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                             |
|  | <ul style="list-style-type: none"> <li>Indicate the direction of the current in circuit diagrams using conventional current</li> <li>Define current (I) as the rate of flow of charge. It is measured in ampere (A), which is the same as coulomb's per second.</li> </ul> <p>Calculate the current flowing using the equation: <math>I = \frac{Q}{t}</math></p> <ul style="list-style-type: none"> <li>Draw a diagram to show how to connect an ammeter in order to measure the current through a given circuit element.</li> </ul>                                                                                                            |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                             |
|  | Voltage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                             |
|  | <ul style="list-style-type: none"> <li>Define potential difference in terms of work done and charge.</li> </ul> <p>Do calculations using the equation: <math>V = \frac{W}{Q}</math></p> <ul style="list-style-type: none"> <li>Know that the voltage measured across the terminals of a battery when no current is flowing through the battery is called the emf.</li> <li>Know that the voltage measured across the terminals of a battery when current is flowing through the battery is called terminal potential difference</li> <li>Draw a diagram to show how to connect a voltmeter correctly in order to measure the voltage</li> </ul> |                                                                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>The sum of the voltages across the external circuit plus the voltage across the internal resistance is equal to the emf:</li> </ul> $\varepsilon = V_{\text{load}} + V_{\text{internal resistance}}$ $\therefore \varepsilon = IR_{\text{ext}} + Ir$ |

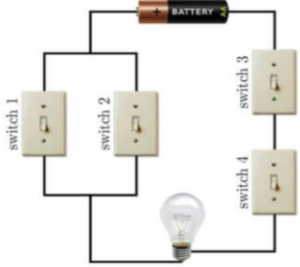
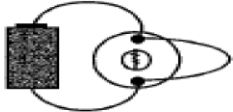
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|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      | across a given circuit element.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                       |                                                                                                                                                                                                             |
| Energy               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                       |                                                                                                                                                                                                             |
|                      | <ul style="list-style-type: none"> <li>• Explain why a battery in a circuit goes flat eventually by referring to the energy transformations that take place in the battery and the resistors in a circuit.</li> </ul>                                                                                                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>• Know that electrical energy is given by <math>E = Pt</math> and is measured in joules. (J)</li> <li>• Solve problems involving the concepts of electrical energy.</li> </ul> |                                                                                                                                                                                                             |
| Resistance           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                       |                                                                                                                                                                                                             |
|                      | <ul style="list-style-type: none"> <li>• Define resistance as the opposition of the flow of electric current.</li> <li>• Define the unit of resistance: One ohm (<math>\Omega</math>) = 1 volt per ampere (V/A)</li> <li>• Give a microscopic description of resistance in terms of electrons moving through a conductor colliding with the particles of which the conductor (metal) is made and transferring kinetic energy.</li> <li>• State and explain factors that affect the resistance of a substance.</li> </ul> |                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>• State that a real battery has internal resistance</li> <li>• Solve circuit problems in which the internal resistance of the battery must be considered.</li> </ul> |
| Series connections   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                       |                                                                                                                                                                                                             |
|                      | <ul style="list-style-type: none"> <li>• Know that current is constant through each resistor in series circuit.</li> <li>• Know that series circuits are called voltage dividers because the total potential difference is equal to the sum of the potential difference across all the individual components.</li> <li>• Calculate the equivalent resistance of resistors connected in series using:<br/><math>R_s = R_1 + R_2 + R_3 + R_4</math></li> </ul>                                                             | <ul style="list-style-type: none"> <li>• Solve problems using the mathematical expression of Ohm's Law (<math>R = V/I</math>) for series circuits</li> </ul>                                                          | <ul style="list-style-type: none"> <li>• Solve circuit problems with internal resistance involving series-parallel networks of resistors.</li> </ul>                                                        |
| Parallel connections |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                       |                                                                                                                                                                                                             |
|                      | <ul style="list-style-type: none"> <li>• Know that voltage is constant across resistors connected in parallel</li> <li>• Know that a parallel circuit is called a current divider because the total current in the circuit is equal to the sum of the branch currents</li> <li>• Know that for two resistors</li> </ul>                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>• Solve problems using the mathematical expression of Ohm's Law (<math>R = V/I</math>) for parallel circuits</li> </ul>                                                        | <ul style="list-style-type: none"> <li>• Solve circuit problems with internal resistance involving series-parallel networks of resistors.</li> </ul>                                                        |

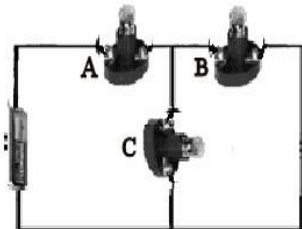
|  |                                                                                                                                                                                                                                                                                                                                  |  |  |
|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|
|  | <p>connected in parallel, the total resistance can be calculated using:</p> $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$ <p>• Calculate the equivalent (total) resistance of resistors connected in parallel using:</p> $R_p = \frac{\text{product}}{\text{sum}} = \frac{R_1 R_2}{R_1 + R_2}$ |  |  |
|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|

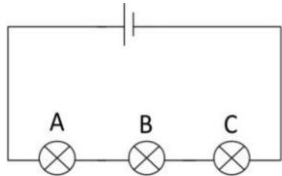
## 7.4 ANNEXURE D Illustration of Common Misconceptions

| No. | Misconception                                                                                                                                                                                                                                                                                                                                                                                          | Misconception as a Mental Model                                                                                                                           | Supporting Literature                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.  | <p><b>Current Consumption Model:</b><br/> <i>Also known as the Weakening Current Model and Attenuation Model.</i><br/>           In this model students believe that current flows in one direction around a circuit, but that the current gradually weakens, because each device in the circuit uses up some of the current until it returns to the battery, where there is no more current left.</p> |                                                                        | <p>Steinberg, 1983<br/>           Osborne &amp; Freyberg, 1985<br/>           Shipstone &amp; Driver, 1985<br/>           Bourges &amp; Gilbert, 1999<br/>           Engelhardt &amp; Beichner, 2003.<br/>           Sencar &amp; Eryilmaz, 2003<br/>           Koltsakis &amp; Pierratos, 2006<br/>           Ümit, <i>et al.</i>, 2011<br/>           van Niekirk, 2011<br/>           Karpazianis &amp; Kriek, 2012<br/>           Bernhardt &amp; Carstensen, 2015</p> |
| 2.  | <p><b>Battery as a Constant Current Source Model:</b><br/>           Students believe that the battery supplies the same amount of current, regardless of the current's arrangement. They fail to discern between the battery as a constant source of voltage, compared to that of a constant source of current.</p>                                                                                   |  <p style="text-align: center;"><math>I_1 = I_2 = I_3 = I_4</math></p> | <p>Cohen, <i>et al.</i>, 1983<br/>           Psillos, <i>et al.</i>, 1988<br/>           Engelhardt &amp; Beichner, 2003.<br/>           Sencar &amp; Eryilmaz, 2003<br/>           Ümit, <i>et al.</i>, 2011<br/>           Karpazianis &amp; Kriek, 2012<br/>           Bernhardt &amp; Carstensen, 2015</p>                                                                                                                                                             |
| 3.  | <p><b>Sink Model:</b><br/> <i>Also known as the Complete Circuit Model and Unipolar Model.</i><br/>           In this model students believe that only one conducting wire would be needed between a battery and a light bulb, in order to produce a current.</p>                                                                                                                                      |                                                                      | <p>Osborne &amp; Freyberg, 1985<br/>           Bourges &amp; Gilbert, 1999<br/>           Engelhardt &amp; Beichner, 2003.<br/>           Sencar &amp; Eryilmaz, 2003<br/>           Koltsakis &amp; Pierratos, 2006<br/>           Ümit, <i>et al.</i>, 2011<br/>           Karpazianis &amp; Kriek, 2012<br/>           Bernhardt &amp; Carstensen, 2015</p>                                                                                                             |

|    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                      |                                                                                                                                                                                                                                             |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4. | <p><u>The Clashing Currents Model:</u><br/>Students believe that positive electricity moves from the positive terminal and simultaneously negative electricity moves from the negative terminal of the power supply. The positive and negative electricity will meet at a device (i.e. light bulb) and clash, thereby powering the device. With this model, research (Bull, et al.2010) has also indicated that students perceive electrons as carrying positive charge.</p> |   | <p>Osborne &amp; Freyberg, 1985<br/>Bourges &amp; Gilbert, 1999<br/>Sencar &amp; Eryilmaz, 2003<br/>Koltsakis &amp; Pierratos, 2006<br/>Ümit, <i>et al.</i>,2011<br/>Karpazianis &amp; Kriek, 2012<br/>Bernhardt &amp; Carstensen, 2015</p> |
| 5. | <p><u>The Shared Current Model:</u><br/>Students believe that current is shared equally amongst a series of identical light bulbs, and consequently these light bulbs will all shine with the same intensity.</p>                                                                                                                                                                                                                                                            |   | <p>Osborne &amp; Freyberg, 1985<br/>Sencar &amp; Eryilma, .2003<br/>Koltsakis &amp; Pierratos, 2006<br/>Ümit, <i>et al.</i>,2011<br/>Karpazianis &amp; Kriek<br/>Bernhardt &amp; Carstensen, 2015</p>                                       |
| 6. | <p><u>The Sequential Model:</u><br/>Students believe that only changes before a circuit device will affect that element. i.e. changes will be carried out in a forward direction, and not backwards.</p>                                                                                                                                                                                                                                                                     |  | <p>Shipstone, 1984<br/>Engelhardt &amp; Beichner, 2003<br/>Sencar &amp; Eryilmaz.2003<br/>Karpazianis &amp; Kriek, 2012</p>                                                                                                                 |

|    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                         |                                                                                                                                                 |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 7. | <p><u>The Local Reasoning Model:</u><br/>Students tend to focus their attention entirely upon what is happening at one point in a circuit, completely neglecting what is happening elsewhere in the circuit. From this Model it is most common that students struggle to view the electric circuit as a system, where every circuit device works together with others and that a change within the one device will affect the whole circuit.</p>                                                                                                                        | <p>Students might argue that by switching switch 1 off will not affect the light bulb as it is not part of the parallel connection.</p> | <p>Cohen, <i>et al.</i>, 1983<br/>Sencar &amp; Eryilmaz, 2003<br/>Karpatzianis &amp; Kriek, 2012<br/>van Niekerk, 2011<br/>Wainwright, 2007</p> |
|    | <p>This form of localised reasoning makes solving circuit problems problematic.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                      |                                                                                                                                                 |
| 8. | <p><u>The Short Circuit Model:</u><br/>Within this model students believe that wire connections without devices attached to the circuit are irrelevant and can be ignored.</p>                                                                                                                                                                                                                                                                                                                                                                                          |                                                     | <p>Shipstone, <i>et al.</i>, 1988<br/>Engelhardt &amp; Beichner, 2003<br/>Sencar &amp; Eryilmaz, 2003</p>                                       |
| 9. | <p><u>Resistive Superposition Misconception:</u><br/><i>Also known as the Rule Application Error and the Parallel Circuit Misconception Model.</i><br/>Students tend to misapply a rule regarding electric circuits. Some students tend to believe that one resistor reduces the current and by adding two resistors the <i>current will be reduced</i> with a factor of two, regardless of the resistor's arrangement. Or students tend to believe that in adding a resistance in a parallel connection, the <i>total resistance of the circuit will increase</i>.</p> |                                                                                                                                         | <p>Engelhardt &amp; Beichner, 2003<br/>Sencar &amp; Eryilmaz, 2003<br/>Karpatzianis &amp; Kriek, 2012</p>                                       |

|     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                     |                                                                                                                                                                                        |
|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10. | <p><u>Topology:</u><br/>         Within this misconception students tend to believe that all resistors that are lined up in series, are in series, whether there is a junction or not. It is also believed within this misconception that all resistors lined up geometrically in parallel are in parallel, even if a battery is contained within a branch.</p>                                                                                                              |  | <p>Engelhardt &amp; Beichner, 2003<br/>         Karpatzianis &amp; Kriek, 2012</p>                                                                                                     |
| 11. | <p><u>Term Confusion:</u><br/>         Students tend to confuse the terms that are characteristic of DC-Circuits:<br/>         Voltage or resistance is viewed as properties of current (<math>I/V</math>) and (<math>I/R</math>). Therefore, if there isn't any flow of current inside a resistor, then the resistor has zero resistance. Students also confuse electric charge with that of electric energy. Students also tend to view voltage to be same as current.</p> |                                                                                     | <p>Engelhardt &amp; Beichner, 2003<br/>         Karpatzianis &amp; Kriek, 2012<br/>         Bull, <i>et al.</i>, 2010<br/>         van Niekerk, 2011<br/>         Wainwright, 2007</p> |

|     |                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                    |                                                                  |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| 12. | <p><u>Empirical Rule Model:</u><br/>This misconception arises from the Current Consumption Model, where it is believed that the further a light bulb is from the battery, the dimmer it will shine.</p> | <p>Students might argue that C is closer to the negative terminal of the battery, therefore it will get electrons first and will consequently glow more brightly. Bulb B will be dimmer and A the weakest.</p>  | <p>Sencar &amp; Eryilmaz, 2003<br/>Ümit, <i>et al.</i>, 2011</p> |
| 13. | <p><u>Battery origin:</u><br/>Students assume that the battery is a source of mobile charge (current), where charges are being 'pumped' out by the power supply, rather than be recycled</p>            |                                                                                                                                                                                                                                                                                                    | <p>Wainwright, 2007<br/>Zimmerman, 2015</p>                      |

ANNEXURE E: ASSESSMENT FRAMEWORK: TEST ITEMS

| ITEM | ITEM TYPE | OPTIONS | MAX POINTS | KEY | OBJECTIVE                       | MISCONCEPTION TESTED                                                             | START | WIDTH |
|------|-----------|---------|------------|-----|---------------------------------|----------------------------------------------------------------------------------|-------|-------|
| 1.   | MC        | 4       | 1          | D   | Current                         | Attenuation Model                                                                | 16    | 1     |
| 2.   | MC        | 3       | 1          | B   | Energy                          | Power supply as constant current source / Local reasoning / Shared current model | 17    | 1     |
| 3.   | MC        | 5       | 1          | C   | Energy                          | Parallel Circuit Misconception                                                   | 18    | 1     |
| 4.   | MC        | 5       | 1          | D   | Physical aspects of DC-circuits | Parallel Circuit Misconception                                                   | 19    | 1     |
| 5.   | MC        | 3       | 1          | B   | Physical aspects of DC-circuits | Parallel Circuit Misconception                                                   | 20    | 1     |
| 6.   | MC        | 5       | 1          | E   | Potential difference            | Weakening current model / Power Supply as constant current source                | 21    | 1     |
| 7.   | MC        | 3       | 1          | A   | Potential difference            | Battery as constant current source Model                                         | 22    | 1     |
| 8.   | MC        | 3       | 1          | C   | Current                         | Weakening current model / Sequential Model                                       | 23    | 1     |
| 9.   | MC        | 5       | 1          | D   | Physical aspects of DC-circuits | Uni-Polar Model                                                                  | 24    | 1     |
| 10.  | MC        | 5       | 1          | E   | Physical aspects of DC-circuits | Short-Circuit Misconception                                                      | 25    | 1     |
| 11.  | MC        | 4       | 1          | A   | Current                         | Local Reasoning                                                                  | 26    | 1     |
| 12.  | MC        | 5       | 1          | D   | Energy                          | Parallel Circuit Misconception / Power supply as constant current source         | 27    | 1     |
| 13.  | MC        | 5       | 1          | A   | Physical aspects of DC-circuits | Parallel Circuit Misconception                                                   | 28    | 1     |
| 14.  | MC        | 3       | 1          | B   | Physical aspects of DC-circuits | Parallel Circuit Misconception                                                   | 29    | 1     |
| 15.  | MC        | 3       | 1          | C   | Potential difference            | Local reasoning / Term confusion                                                 | 30    | 1     |
| 16.  | MC        | 3       | 1          | C   | Potential difference            | Parallel Circuit Misconception                                                   | 31    | 1     |
| 17.  | MC        | 5       | 1          | D   | Current                         | Attenuation Model / Parallel Circuit Misconception                               | 32    | 1     |
| 18.  | MC        | 5       | 1          | C   | Physical aspects of DC-circuits | Short-Circuit Misconception                                                      | 33    | 1     |
| 19.  | MC        | 5       | 1          | C   | Physical aspects of DC-circuits | Short-Circuit Misconception                                                      | 34    | 1     |
| 20.  | MC        | 4       | 1          | D   | Current                         | Local Reasoning                                                                  | 35    | 1     |
| 21.  | MC        | 5       | 1          | D   | Energy                          | Local reasoning / Term confusion                                                 | 36    | 1     |
| 22.  | MC        | 5       | 1          | B   | Physical aspects of DC-circuits | Parallel Circuit Misconception & Confusion of terms                              | 37    | 1     |
| 23.  | MC        | 4       | 1          | C   | Physical aspects of DC-circuits | Confusion of terms / Local Reasoning                                             | 38    | 1     |
| 24.  | MC        | 5       | 1          | D   | Potential difference            | Term Confusion                                                                   | 39    | 1     |
| 25.  | MC        | 3       | 1          | A   | Potential difference            | Battery as constant current source / Empirical rule Model / Term confusion       | 40    | 1     |
| 26.  | MC        | 5       | 1          | D   | Current                         | Sequential reasoning                                                             | 41    | 1     |
| 27.  | MC        | 4       | 1          | B   | Physical aspects of DC-circuits | Short-Circuit Misconception                                                      | 42    | 1     |
| 28.  | MC        | 4       | 1          | D   | Potential difference            | Local reasoning / Term confusion / Battery as constant power supply              | 43    | 1     |
| 29.  | MC        | 5       | 1          | B   | Potential difference            | Parallel Circuit Misconception                                                   | 44    | 1     |

| PF  | QUESTION | QUESTION TYPE | OPTIONS | START | WIDTH | OPTION | MEANING                              |
|-----|----------|---------------|---------|-------|-------|--------|--------------------------------------|
| 1.  | 36       | MC            | 5       | 11    | 1     | A      | Rural                                |
|     |          |               |         |       |       | B      | Township                             |
|     |          |               |         |       |       | C      | Inner city                           |
|     |          |               |         |       |       | D      | Ex model C                           |
|     |          |               |         |       |       | E      | Private school                       |
| 2.  | 37       | MC            | 5       | 12    | 1     | A      | African                              |
|     |          |               |         |       |       | B      | English                              |
|     |          |               |         |       |       | C      | Asian                                |
|     |          |               |         |       |       | D      | Afrikaans                            |
|     |          |               |         |       |       | E      | OTHER                                |
| 3.  | 38       | MC            | 5       | 13    | 1     | A      | 7 (> 80%)                            |
|     |          |               |         |       |       | B      | 6 (70-79%)                           |
|     |          |               |         |       |       | C      | 5 (60-69%)                           |
|     |          |               |         |       |       | D      | 4 (50-59%)                           |
|     |          |               |         |       |       | E      | 3 (< 50%)                            |
| 4.  | 39       | MC            | 5       | 14    | 1     | A      | 7 (> 80%)                            |
|     |          |               |         |       |       | B      | 6 (70-79%)                           |
|     |          |               |         |       |       | C      | 5 (60-69%)                           |
|     |          |               |         |       |       | D      | 4 (50-59%)                           |
|     |          |               |         |       |       | E      | 3 (< 50%)                            |
| 5.  | 40       | MC            | 5       | 15    | 1     | A      | 7 (> 80%)                            |
|     |          |               |         |       |       | B      | 6 (70-79%)                           |
|     |          |               |         |       |       | C      | 5 (60-69%)                           |
|     |          |               |         |       |       | D      | 4 (50-59%)                           |
|     |          |               |         |       |       | E      | 3 (< 50%)                            |
| 6.  | 41       | MC            | 5       | 11    | 1     | A      | B.Eng                                |
|     |          |               |         |       |       | B      | MBChB                                |
|     |          |               |         |       |       | C      | B.Sc (Biological Sciences)           |
|     |          |               |         |       |       | D      | B.Sc (Physical Sciences)             |
|     |          |               |         |       |       | E      | B.Sc (Extended programme)            |
| 7.  | 42       | MC            | 5       | 12    | 1     | A      | PHY 131                              |
|     |          |               |         |       |       | B      | PHY 114                              |
|     |          |               |         |       |       | C      | PHY 133                              |
|     |          |               |         |       |       | D      | FSK 116                              |
|     |          |               |         |       |       | E      | OTHER                                |
| 8.  | 43       | MC            | 5       | 13    | 1     | A      | Group work                           |
|     |          |               |         |       |       | B      | Demonstration                        |
|     |          |               |         |       |       | C      | Teacher gave reading from book       |
|     |          |               |         |       |       | D      | Travelling laboratory visited school |
|     |          |               |         |       |       | E      | Visited another school/institution   |
| 9.  | 44       | MC            | 2       | 14    | 1     | A      | Male                                 |
|     |          |               |         |       |       | B      | Female                               |
| 10. | 45       | MC            | 4       | 15    | 1     | A      | Like physics, good at it             |
|     |          |               |         |       |       | B      | Like physics, not good at it         |
|     |          |               |         |       |       | C      | Don't like physics, good at it       |
|     |          |               |         |       |       | D      | Don't like physics, not good at it   |

